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1. INTRODUCTION

The construction of dams and the diversion of water had become an extraordinarily important aspect of man's activities by the beginning of the third millenium B.C. The birth of civilization along the rich alluvial deposits of the Nile and the Tigris and Euphrates was the result of water diversion for concentrated irrigated agriculture. With the much later advent of hydroelectric generation many of the world's major water courses were for power generation. In most industrial countries, series of dams along entire river systems provide a very significant portion of the total power generation. Their environmental impacts have often been very great (Goldman 1976, 1979, 1981; Goldman et al. 1973). Still, there remains a great deal of hydroelectric potential particularly in Asia, Africa, South and Central America and New Guinea (Goldman and Hoffman 1977). Although much has been learned from studies of the great African dams (Nassar, Volta, Kariba and Kainji), well integrated studies covering the great diversity of ecological impacts in the tropics have been rare. The El Cajón high dam has afforded a rare opportunity to study the ecological aspects of the area before and after dam construction and reservoir impoundment.

The El Cajón dam will be the highest dam on the American continent (226 m) and the fourth highest arch dam in the world. The ultimate capacity of this installation could eventually be 600 MW of electrical power, which is enough to provide much of the needed power for Honduras and perhaps supply a surplus for export to its neighbors. The dam is located on the seismically active Caribbean Plate and has been specially designed to withstand earth tremors at the dam of 0.32 g. This is particularly important because increased seismic activity from the enormous weight of water on the earth's crust may result after the reservoir is filled. The reservoir is also intended to provide needed flood control and irrigation water for the Sula valley below.

The El Cajón project differed from many similar hydroelectric projects by including in the early planning stage a feasibility study to consider the most likely ecological consequences of the project. This study was undertaken by Ecological Research Associates (ERA) of Davis, California and began with a reconnaissance of the El Cajón dam site in August of 1972. The six person team, led by Professor Charles R. Goldman, considered physical and chemical aspects of the project as well as the biological. Human ecology, particularly as it related to health and resettlement, was included. Archeology, recreation and possible tourism were also included. Further, the possible downstream consequences of the El Cajón dam and reservoir were also discussed in the report which appeared in December (Goldman 1972).

On the basis of recommendations from this report, a limnology laboratory was designed, equipped and established at Santa Cruz de Yojoa in July 1979, in order to undertake a wide-ranging limnological and fisheries study of the rivers and lakes in the El Cajón area. ERA was in charge of program operation and supervision. During the first year of the program, the laboratory was directed by ERA resident limnologist Christopher Knud-Hansen and during the second and third years this position was held by Peter Vaux. The direct supervision by ERA of the project ended at the end of 1982. Mr. Ernesto Vargas then took over as Laboratory Director and continues to hold this post. Informal communications with the projects have been continued by ERA, the Inter-institutional Coordinator and the Laboratory Director.

Three scientists (all biologists) from the National University in Tegucigalpa joined the program at its inception. Subsequently, a chemist was recruited to bring the total number of scientists working at the laboratory to five. Coordination of the Limnology and Fisheries Program within the broader framework of the El Cajón environmental studies was provided by Inter-institutional Coordinator Ing. Armando Berlíoz of ENEE. Strong support throughout the life of the project was provided by Dr. Christian Zimmermann, senior ecologist for Motor Columbus Consulting Engineers, Inc., Baden, Switzerland. Professor Goldman was responsible for planning and directing the Limnology and Fisheries program and made regular visits to the project.

The principal objective of the Limnology and Fisheries Program was to build a data base which would be used both to predict limnological characteristics of the future El Cajón reservoir and to serve as a foundation for the establishment of medium- to long-term management policies and essential studies for both the lake and its watershed. A second objective was to train Honduran biologists in limnology and fisheries. During the course of the study three of the biologists visited the University of California, Davis and one, Gladys Yong Chú Stewart has almost completed a Masters degree on the zooplankton population of Lago Yure.

The program was divided into three component parts. The first of these was a monitoring study of the water quality of the three major rivers which will form the new El Cajón reservoir, the Humuya, Yure and Sulaco. Frequent sampling near the dam site was complemented by a network of stations throughout the watershed which were sampled at approximately monthly intervals during the first year of the program.

The second component of the program was a series of limnological studies on two contrasting lake systems in the El Cajón area, Lago Yure and Lago de Yojoa. The first of these is a small reservoir which has a number of relative morphological characteristics similar to those of the future Lago El Cajón. Lago de Yojoa is the largest natural lake in Honduras. Although it has approximately the same area as the future reservoir, its morphology is quite different. A comparative series of investigations into the physical limnology, water quality, primary productivity and plankton community structure of these two lakes provided an extremely valuable foundation through which the data base resulting from the river water quality monitoring program could be better interpreted and related to the future limnology of the El Cajón reservoir.

The third major component of the program was a study of the biology and ecology of the fish species occurring in the El Cajón area. As with the river water quality monitoring program, a few frequently sampled stations were complemented by a series of fish collections throughout the basin of the future reservoir. Special emphasis was given to the developing fishery of Lago Yure in order to better understand how some of the native species were adapting to a recently created lacustrine environment as evidence of their likelihood of success in the new El Cajón reservoir.

Analysis of most of the samples collected during the 2 1/2 year program were carried out by the five scientists working at the Santa Cruz laboratory. This work was supplemented by identification of invertebrates, isotope work, and certain chemical analyses in Davis, California. Preliminary data analysis was assisted by acquisition of a Hewlett-Packard desk-top programable calculator and plotter. A series of computer programs were developed for the project by E.R.A. who also trained the personnel to operate the instrument during a four day visit of ERA computer specialist, E. de Amezaga, in March 1981.

The Limnology and Fisheries Program represented what was certainly the first major limnological study to be carried out in Honduras. It soon became clear that the greatest benefits would be derived from the program if the base of information and experience that was being assembled was used to formulate and eventually execute rational management policies for the El Cajón and any future impoundment projects that might be planned.

A number of aspects of the program promoted this objective. The series of studies carried out on L. Yure and L. de Yojoa were important in terms of obtaining a comparative data base for subsequent integration with the river water quality monitoring program. They also represented a major opportunity for the Honduran scientists working in the program to accumulate a solid base of limnological experience. This is an aspect of the study that would have been impossible if the research effort had been restricted to riverine systems. Thus the program personnel are now in a good position to continue with an important series of investigations during the crucial post-impoundment phase (PIP) of the El Cajón reservoir studies.

During the course of the Limnology and Fisheries Program, considerable effort was made to cooperate with other Honduran agencies that, in one way or another, were connected with aquatic resource management. A number of talks on ecological aspects of the El Cajón project were given by the program scientists to groups at the National University in Tegucigalpa and, in 1981, a short limnology field course was organized for university students. This course was based at the Santa Cruz laboratory and at L. Yure. In September 1981, a one day symposium was held in Tegucigalpa, at which the various environmental programs of the El Cajón project were discussed with interested parties as well as the general public. Members of the Limnology and Fisheries Program, together with the Inter-institutional Coordinator, Ing. Armando Berlioz, were instrumental in developing this symposium.

A limnological "reconnaissance" study of the main water supply reservoir in Tegucigalpa, Los Laureles, was carried out for the Honduran water supply authority, SANAA, in 1981 and 1982. Additional short studies were also undertaken for ENEE. For example, an environmental impact study for the Tamalito river diversion project was started in 1981. Its integration within the main El Cajón sampling framework was made possible by hiring additional staff to carry out much of the Tamalito field work. This study did not continue for as long as originally planned since ENEE decided not to proceed with the diversion project at that time. The water chemistry data collected during this study are, however, presented as an appendix to this report, in case there is a future re-activation of this project.

A short study of the problem of Eichhornia infestation at the southern end of L. de Yojoa was also undertaken for ENEE. A fenced "corridor" was recommended as a more effective and less expensive way of keeping the Varsovia-Yojoa canal open than the originally-planned purchase of mechanical harvesting equipment.

In view of the impact of land management practices on lake systems, especially the future El Cajón reservoir, it was considered very important to develop a joint study with the Honduran Forestry Corporation, COHDEFOR, on the influence of land management practices on runoff water quality. Initial attempts to fund such a collaborative study were unsuccessful. However, more recently, staff of the Limnology Laboratory have initiated a study with COHDEFOR to investigate runoff water quality in the L. Yure watershed. The potential value for future work in this area is very great and further integration of limnological-based studies into the context of land management represents what could be one of the most important aspects of the future development of the limnology program.

The data-base developed during the course of the Limnology and Fisheries Program is extensive and covers a broad range of studies. The purpose of this report is to present and analyze the main body of collected data, to integrate it with reference to the El Cajón reservoir and to suggest a series of studies which are essential for adequately understanding the dynamics and ecology of the new lake.

The complexity of lake systems and the necessarily broad nature of this program have resulted in the identification of a wide series of limnological processes which will need further investigation in order to be able to assess their full importance, both for the two lakes already studied and for the El Cajón reservoir. One of the aims of this report is to emphasize those areas where future research and monitoring efforts are most needed.

The data collected during the fisheries study, section 11, are extensive and are presented in the second volume of this report. Recommendations for future fisheries work are, however, included in section 3 of the present volume. The limnological data are discussed in the five major sections of this volume. Section 4 presents an overview of the whole program by summarizing the sampling schedule and station network used in each of the component studies. Methodology employed for these studies is presented in section 5. Section 6 presents and analyzes data collected during the river water quality monitoring program. The limnological studies carried out on L. Yure and L. de Yojoa are discussed in sections 7 and 8 respectively. Section 9 is a synthesis of the entire limnological data-base and discusses major aspects of the future limnology of the El Cajón reservoir through an integration of the lake and river studies. Section 10 presents the results of a small study carried out on the invertebrate fauna of a stream entering the R. Humuya just downstream from the dam site. Summary tables and figures in the main body of the text present much of the data, but a more extensive data record is placed in a series of appendices, which also include detailed descriptions of some of the methodology developed for and employed in the program.

The synthesis, section 9, is extended into a series of studies recommended for Lago El Cajón which, by adding to the already existing data-base, are designed to shed more light on various aspects of the new reservoir ecosystem. These recommendations appear in section 3 and can form the basis for the ongoing post-impoundment phase of limnological and fisheries studies directed towards further developing and optimizing a management strategy for Lago El Cajón. The full potential of this extraordinarily important new National resource for Honduras can only be achieved through further development of a truly integrated, interdisciplinary management program directed towards the entire reservoir catchment basin as well as the reservoir itself. This report, although focused on Limnology and Fisheries, is a step towards this goal.

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1. INTRODUCCION

Desde el principio del tercer milenio A.C., la construcción de represas y diversión de agua ha llegado a ser un aspecto extraordinariamente importante en la actividad humana. La diversión de agua para la irrigación agrícola intensa dio lugar al florecimiento de civilizaciones a lo largo de los ricos depositos aluviales del Nilo, Tigris y Eufrates. Luego con el advenimiento de la generación hidroeléctrica muchos de las grandes cauces fluviales del mundo han sido represados para la generación de poder. En los paises industrializados, una serie de represas a lo largo del sistema fluvial provee una muy significativa porción del total del poder generado y cuyos impactos ambientales han sido enormes (Goldman 1976a, 1979, 1981; Goldman et al. 1973). Sin embargo queda aun mucho potencial hidroeléctrico particularmente en Asia, Africa, Centro y Suramerica y Nueva Guinea (Goldman y Hoffman 1977). Aunque mucho se ha aprendido de los estudios de las grandes represas de Africa (como ejemplos Nassar, Volta, Kariba y Kainji), raros han sido los estudios integrados que abarquen la gran diversidad de impactos ecológicos en la zona tropical. La gran represa de El Cajón ha brindado una oportunidad excepciónal para el estudio de los aspectos ecológicos en el aŕea antes y después de la construción de la represa y el llenado del embalse.

La represa de El Cajón será la represa más alta del continente americano (de 226 m.) y el cuarto en elevación del arco de la represa en el mundo. Eventualmente, la capacidad final de esta instalación podría ser de 600 MW de energía eléctrica, el cual será más que suficiente para proveer la energía necesaria para Honduras y suplementar quizás un exceso para la exportación a paises vecinos. La represa está localizada en la Placa sísmicamente activa del Caribe y ha sido disenada especialmente para resistir temblores de tierra en la represa de unos 0.32 g. Esto es de particular importancia pues luego que el embalse se llene, el peso enorme del agua sobre la corteza terrestre podría incrementar la activida sísmica. El embalse también podría proveer agua para irrigacióon y el requerido control de inundación por debajo del Valle de Sula. El proyecto de El Cajón difiere de otros proyectos hidroeléctricos similares al incluir en su etapa previa de planeamiento un estudio de factibilidad, el cual considera las posibles consequencias ecológicas del proyecto. El estudio fue emprendido por el Ecological Research Associates (ERA) de Davis en California y empezó con un reconocimiento del sitio de la represa de El Cajón en agosto de 1972. Los aspectos físicos y químicos del proyecto como también los biológicos fueron considerados por un equipo de seis personas dirigidos por el Profesor Charles R. Goldman. Factores de la Ecología Humana, particularmente relacionados con salud y reubicación fueron incluidos. Comprendidos también fueron antropología, recreación y posible turísmo. Asimismo las posibles consecuencias de la represa de El Cajón y el embalse río abajo fueron así discutidos en el reporte publicado en diciembre (Goldman 1972).

Basados en las recomendaciones de este reporte, un laboratorio limnológico fue designado, equipado y establecido en Santa Cruz de Yojoa en julio de 1979, cuya función es emprender un amplio estudio de limnología y de peces en los ríos y lagos del área de El Cajón. El programa de operación y supervisión estuvo a cargo del ERA. Durante el primer ano del programa, el laboratorio fue conducido por el limnólogo residente del ERA Sr. Christopher Knud-Hansen y luego la dirección fue tomada por el Sr. Peter Vaux durante el segundo y tercer ano. La supervisión directa del proyecto por el ERA terminó a finales de 1982. Asi pues el Sr. Ernesto Vargas tomo posición como Director del Laboratorio y aún continua manteniendo este puesto. A traves del coordinador inter-institucional y del director del laboratorio, el ERA ha continuado comunicaciones informales con el proyecto.

Desde su comienzo, tres científicos (todos biólogos) de la Universidad

Nacional Autónoma en Tegucigalpa se incorporaron al programa. Subsecuentemente, un químico fue incluido al personal brindando asi un número total de científicos laborando en el laboratorio de cinco. La coordinación del programa limnológico y de peces dentro de un amplio esquema de los estudios ambientales de El Cajón fue proporcionada por el coordinador inter-institucional Ing. Armando Berlíoz de la E.N.E.E. Un firme apoyo a lo largo del proyecto fue provisto por el Dr. Christian Zimmermann, ecólogo experimentado del Motor Columbus Consulting Engineers, Inc. de Bèden en Suiza. La responsabilidad del planeamiento y dirección del programa limnológico y de pesca recae en el profesor Goldman quien hizo visitas regulares al proyecto. El objetivo primordial del programa limnológico y de pesca fue el construir datos básicos los cuales podrían ser usados primero para predecir las características limnológicas futuras del embalse de El Cajón, en segundo lugar serviría como fundamento para el establecimiento de políticas de manejo de mediano a largo plazo y tercero senalar estudios esenciales para ambos el lago y su cuenca. Un objetivo secundario fue el entrenamiento de biólogos hondurenos en limnología y pesca. Durante el curso del estudio, tres de los biólogos visitaron la Universidad de California en Davis y una, Sra. Gladys Yong-Chú Stewart casi ha completado su Maestría sobre las poblaciones de zooplancton en el lago Yure. El programa fue dividido en tres partes componentes. El primero de ellos fue un estudio monitor de la calidad de agua en los tres principales ríos que formarán el nuevo embalse de El Cajón, que son los ríos Humuya, Yure y Sulaco. Los muestreos frecuentes cerca del sitio de la represa fueron complementados con una red de estaciones a lo largo de la cuenca los cuales fueron muestreados aproximadamente a intervalos mensuales durante el primer ano del programa. El segundo componente del programa fue una serie de estudios limnológicos de dos sistemas lacustres desemejantes en el área de El Cajón, el lago Yure y lago de Yojoa. El primero es un pequeno embalse el cual presenta una cantidad de caracterfsticas morfológicas similares a aquellas del futuro lago de El Cajón. El lago de Yojoa es el lago natural más grande de Honduras. A pesar de ser este de un área aproximada al futuro embalse, su morfología es bastante diferente. Una serie de investigaciones comparativas de los dos lagos en cuanto a sus características físicas limnológicas, calidad de agua, productividad primaria y estructura de la comunidad del plancton ha proporcionado un fundamento extremadamente valioso; asi mismo estos en conjunto con los datos básicos recogidos durante el programa monitor de calidad de agua de los ríos podría resultar en una mejor interpretación y relación con la limnología del futuro embalse de El Cajón. El tercer componente del programa fue el estudio de la Biología y Ecología de las especies de peces presentes en el área de El Cajón. En adición al programa monitor de calidad de agua de los ríos, se seleccionaron algunas estaciones de muestreo frecuente los cuales fueron complementados con una serie de colecciones de peces a lo largo de la cuenca del futuro embalse. Un énfasis especial fue dado al desarrollo de la pesca en el lago Yure para ganar un mejor entendimiento de los procesos adaptativos de algunas especies nativas en el recien creado ambiente lacustre así como evidencia de su posible buen éxito en el nuevo embalse de El Cajón. Los cinco científicos que laboraron en el laboratario de Sta. Cruz durante los dos anos y medio del programa realizaron el análisis de la mayoría de las muestras colectadas. Esta labor fue suplementada por la identificación de invertebrados, trabajo con isótopes radioactivos y ciertos análisis químicos en Davis, California. Los análisis preliminares de los datos fueron asistidos por la adquisición de una computadora programable marca Hewlett-Packard y una máquina para graficar. Una serie de programas para la computadora fue desarrollada para el proyecto por el ERA y el entrenamiento del personal en el uso de los equipos fue realizada por el especialísta en computadoras del ERA, Sra. E. de Amezaga durante su visita de cuatro días en marzo de 1981.

El programa de limnología y lo peces represento lo que ciertamente fue el primer estudio limnológico más significativo e importante que se ha llevado a cabo en Honduras y quizás en Centro America. Se esclarecerá rápidamente que los mayores beneficios derivadas del programa serían si la información básica y la experiencia reunidas fueran utilizados para la formulación y eventualmente ejecución de politicas de manejo racionales para El Cajón o cualquier otro proyecto de embalsamiento futuro. Una cantidad de aspectos del programa promovieron este objetivo, por ejemplo la serie de estudios realizado en los lagos Yure y Yojoa no solo fueron importantes en términos de la obtención de datos comparativos básicos sino también para la integración subsecuente con el programa monitor de calidad de agua de los ríos. Ello representa una gran oportunidad para los científicos hondurenos trabajando en el proyecto debido a la acumulación de una base sólida en experiencia limnológica. Este es un aspecto del estudio que podría haber sido imposible si el esfuerrzo investigativo hubiera sido restringido solo al sistema fluvial. En consecuencia el personal del programa está ahora en una posición de continuar con una serie de investigaciones importantes durante la fase crucial posterior al embalsamiento (llamado por sus siglas en ingles PIP (post-impoundment phase)) de los estudios del embalse de El Cajón. Durante el curso del programa de limnología y de peces, un esfuerzo considerable fue invertido en la cooperación con otras agencias hondurenas que en una u otra manera estuvieron conectados con el manejo de los recursos acuáticos. Varias charlas sobre los aspectos ecológicos del proyecto de El Cajón fueron ofrecidos por los científicos del programa a grupos de la Universidad Nacional Autónoma en Tegucigalpa y en 1981 fue organizada un breve curso de limnológia práctica para los estudiantes universitarios. La base del curso fue en el laboratorio de Sta. Cruz y en el lago Yure. En septiembre de 1981, un simposio de una día fue realizado en Tegucigalpa, durante el cual los diversos programas ambientales del proyecto de El Cajón fueron discutidos por las partes interesadas así como por el público general. Los miembros del programa de limnología y de peces junto con el coordinador inter-institucional Ing. Armando Berlíoz fueron esenciales en el desarrollo de este simposio.

Un estudio de `reconocimiento' limnológico del principal suplidor de agua en Tegucigalpa el embalse "Los Laureles" fue realizado para las autoridades hondurenas del SANAA en 1981 y 1982. Breves estudios adicionales fueron tambíen emprendidos para la ENEE. Como ejemplo tenemos el estudio del impacto ambiental del programa de diversión del río Tamalito, la dotación de personal adicional fue necesaria para realizar parte del trabajo de campo en el Tamalito. Este estudio no fue completado en la extensión en que fuera planeada inicialmente debido a la decisión de la E.N.E.E. de no proceder con el proyecto de diversión en aquel tiempo. Los datos de la química de agua están presentados como un apéndice en este reporte en caso de haber una futura reactivación de este proyecto.

Un breve estudio sobre el problema de infestación en el extremo sur del lago de Yojoa por Eichhornia fue también llevado a cabo para la E.N.E.E. Un "corredor" cercado fue recomendado como la vía más efectiva y barata para mantener el canal de Varsovia-Yojoa abierta en sustitución de la adquisición de un equipo mecánico de cosecha planeada originalmente.

En vista del impacto en las prácticas de manejo en los sistemas lacustres, especialmente en el futuro embalse de El Cajón fue considerado vital el desarrollar un estudio conjunto con la Corporación Forestal Hondurena COHDEFOR sobre la influencia de las prácticas de manejo de suelos con relación a la calidad del agua que fluye sobre la superficie de los suelos. Intentos iniciales para financiar tal estudio colaborativo fueron un fracaso. Sin embargo, más recientemente, el personal del laboratorio de limnología ha iniciado un estudio conjunto con la COHDEFOR para investigar la calidad de agua que fluye sobre la superficie de la cuenca del lago Yure. El valor potencial sobre futuros trabajos en esta área es muy grande y una mejor integración de estudios básicos limnológicos en el contexto de manejo de suelos representa quizás una de las direcciones más productivas para el futuro desarrollo del programa limnológico.

Los datos básicos desarrollados durante el curso del programa limnológico y de pesca son extensos y cubren un amplio rango de estudios. El propósito de este reporte es el presentar y analizar la mayor parte de los datos colectados e integrarlo con referencia al embalse de El Cajón como también sugerir una serie de estudios que serán esenciales para el entendimiento adecuado de las dinámicas y ecología del nuevo lago.

La complejidad de los sistemas lacustres y la obligada naturaleza amplia del programa dio en consecuencia la identificación de una extensa serie de procesos limnológicos los cuales requerirán de investigaciones adicionales para asi poder determinar su total importancia, para ambos los dos lagos ya estudiados y el embalse de El Cajón. La enfatización de aquellas áreas donde futuras investigaciones son más necesarias, es uno del los aportes de este reporte. Los datos colectados durante el estudio de peces en la sección 11 son extensos y serán presentados posteriormente en el segundo volumen de este reporte. Sin embargo las recomendaciones relacionados con futuros trabajos en peces está incluídos en la sección 3 del presente volumen. Los datos limnológicos son discutidos en cinco secciones de este volumen. En la sección 4 presenta una revisión de todo el programa al resumir el horario de muestreo y la red de e staciones utilizadas en cada uno de los componentes del estudio. La metodología empieada en estos estudios es presentada en la sección 5. La sección 6 da conocer y analiza los datos colectados durante el programa monitor de calidad de agua fluvial. Los estudios limnológicos llevados a cabo en los lagos Yure y Yojoa son discutidos en las secciones 7 y 8 respectivamente. En la sección 9 está la síntesis de todos los datos básicos limnológicos y la discusión sobre los posibles aspectos limnológicos más importantes del embalse de El Cajón a través de una integración de los estudios realizados en lagos y ríos. En la sección 10 muestra los resultados de un pequeno estudio realizado con los invertebrados de una quebrada que afluye al río Humuya justamente río abajo del sitio de la represa. Las figuras y tablas sumarias que representan la mayor parte del texto muestran la mayor parte de los datos; aún así el registro extenso de los datos está colocado en una serie de apéndices, los cuales incluyen descripciones detalladas de diveros métodos desarrollados o empleados en el programa. La síntesis de la sección 9 se extiende en una serie de estudios recomendatorios para el lago de El Cajón, el cual junto con los datos básicos ya existentes están designados a verter más luz en los diversos aspectos del ecosistema del nuevo embalse. Estas recomendaciones aparecen en la sección 3 los cuales podrán formar la base para los estudios limnológicos y de pesca durante la fase en progreso posterior al embalsamiento y dirigir hacia el lago de El Cajón, un mayor desarrollo y optimatización de la estrategia del manejo. Este nuevo recurso nacional extraordinariamente importante para Honduras, alcanzaría su potencial total solamente a través del desarrollo adicional de un programa real integrativo de manejo interdisciplinario orientado hacia toda la cuenca como al propio embalse. Este reporte, aunque enfoca en limnología y en peces, representa un paso hacia esta meta.

AGRADECIMIENTOS

Muchas personas contribuyeron sustancialmente al estudio previo al embalsamiento de El Cajón. El grupo original del laboratorio consistió del

Lic. Gladys Yong Chú Stewart (quien realizó la traducción en español de este reporte), Lic. Efraín Villeda, y Lic. Lydia M. Bendeck bajo la dirección del director del laboratorio de limnología Sr. Christopher Knud-Hansen, quien fue asistido durante su ejercicio por la Srta. Bonnie Combs. Luego Lic. Ernesto Vargas, Lic. Ana-Lizeth Díaz, Lic. Yolanda Valle y Lic. Adela Flores se incorporaron al personal. El entusiasmo e interés demostrados por el personal del laboratorio han sido muy apreciados. Varios miembros de la E.N.E.E. proporcionaron asistencia invaluable, éstos incluyen al Ing. Armando Berlíoz, el coordinador Inter-institucional, Ing. Armando Díaz, director del proyecto de El Cajón, Ing. Bush, Ing. Raúl Flores-Guillen administrador general de la E.N.E.E., Ing. J. Saborío e Ing. Jorge Flores, nuestro motorista Sr. Francisco Reyes y nuestro vigilante en Santa Elena, Sr. José M. Mejía también merecen un agradecimiento especial. De parte del Motor Columbus, el Dr. C. Zimmermann nos suministro una firme, extraordinaria dedicación y aliento a lo largo del programa ecológico. El Ing. H. Kreuzer y más tarde, el Ing. H. Rieder brindaron asistencia en manejo. El Sr. Yves Cuenod, géologo del Motor Columbus maostró interés en el programa y el Ing. Pierre Tafelmacher estuvo siempre dispuesto a proveer asistencia enormemente apreciada hacia el limnológo residente del ERA.

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2. SUMMARY

2.1 INTRODUCTION

2.1.1 The scope of the investigations

This study involved sampling a broad area of the future reservoir and its associated streams and lakes from 1979 through 1982. Particular attention was given to regular sampling of Lago Yure and Lago de Yojoa to improve understanding of the new environment and train Honduras biologists in limnology and fisheries research and management. Because of the relevance of the Lago Yure studies to the future reservoir and Post-Impoundment Program (PIP), L. Yure was sampled every two weeks after the first year, with particular attention to food chain dynamics. River water quality was monitored at 15 stations, including 4 stations located below the dam site. Site locations are shown in Fig. 4.1, and two stations were included on each of the three major rivers (Humuya, Sulaco, and Yure). The station #9 sample at the dam site represented an integration of the various inflows to the new El Cajón reservoir and was most frequently sampled. A small stream, Q. El Cajón, just below the dam site was sampled biweekly during the first year of the study.

In addition, two smaller studies were included in the program. The first was a river diversion/dam project on the Tamalito River (Appendix 6) and the second concerned suspended sediment loading from the Humuya River (section 6.2.6).

Primary productivity was measured at both L. Yure and L. de Yojoa together with phytoplankton and zooplankton. In addition to stream insect larvae, benthic invertebrates from L. Yure were also sampled, since these organisms are very important to the fisheries. Fish populations were studied throughout the watershed to determine their distribution in the watershed. Frequent sampling of Lago Yure and the Río Yure provided important documention of seasonal changes in both reproduction and feeding as well as the development of fisheries in Lago Yure. The details of this extensive fisheries study are included in Volume II as section 11. Fisheries recommendations for the PIP, however, have been included in this volume (3.3).

2.2 METHODS

2.1.2 Physico-Chemical Sampling Methods

Best available sampling and analytical methods were employed. Duplicate samples were routinely collected for stream and lake studies and a third sample was taken for suspended solids analysis. *In situ* measures of conductivity, temperature, and dissolved oxygen were taken routinely and pH was measured soon after sample collection. A current meter provided stream-flow measurements and light penetration was measured by Secchi disc and submersible photometer. Alkalinity, turbidity, suspended solids and fluorescence were measured soon after collection. Cation analysis was performed by atomic absorption spectrometry in Davis, California; other chemical analyses were performed as described in Standard Methods (APHA 1975). A pyrheliograph at Santa Cruz provided a continuous record of solar radiation.

2.2.3 Biological Sampling Methods

Primary productivity (algal photosynthesis) provides a biological integration of the physical and chemical environment, and forms the base of the lake food chain. The 14-Carbon method was used to directly measure productivity, as well as for bioassays of nutrient factors affecting algal growth. Standard oxygen methodology was used to determine Biochemical Oxygen Demand (BOD). Phytoplankton samples were collected both at discrete depths and integrated throughout the light (euphotic) zone. A manual for the inverted microscope procedure was developed (see Appendix 5). Early phytoplankton identification and the development of a laboratory manual was done at Davis. Vertical net tows were used to collect zooplankton, and stream invertebrates were sampled by standard methods.

Fish were collected by electroshocking, seining and graded fleets of gill netting. Cast nets and explosive charges were used in a few cases. Some larger fish were also purchased from local fishermen. Fish were measured, weighed and identified. Stomach contents were analyzed and their volume determined. Fish condition was evaluated by gut accumulation of fat. Reproductive state was also determined for some species. Growth rates were estimated by tagging, cohort size distribution analysis and scale analysis. Recomendations on the fish studies are in section 3.3 and in section 11, Vol. II.

2.3 RIVER WATER QUALITY STUDY

2.3.1 Introduction

The Sulaco drainage covers 56% of the total 8320 square kilometer drainage basin which also includes the Humuya and Yure rivers. Thirty-five % of the V-shaped valleys of the Humuya drainage have slopes greater than 40%. The Sulaco has even a greater percentage of steep slopes. Slash and burn agriculture appears throughout the basin and 38% of the area below 300 m.a.s.l. was forested. Reservoir clearing has now probably amounted to about 50%. The Sula Valley below the El Cajón dam is approximately 26% cultivated and 46% is in pasture or left fallow. Mean dry (January-April and wet season (June - September) values have been calculated for most water quality parameters from a total of 18 stations.

Important generalizations from our studies indicate that the Humuya and Sulaco rivers are quite similar but the Yure differs markedly with lower flow, turbidity, total-P, conductivity, alkalinity and metal content. Nitrogen, however, differs very little between the three streams and may eventually be a limiting factor in the fertility of the new El Cajón reservoir.

2.3.2 Stream temperatures

Typically stream temperatures lagged behind solar radiation and reached their maximum between April and August. The yearly range varied between different streams and locations. Oxygen levels were slightly lower in the wet season than in the dry, but were usually more than 90% saturated.

2.3.3 Conductivity

Conductivity, related to dissolved ions, increased between November and April and decreased between May and September. This reflects the greater percentage of groundwater entering the stream during the dry season. Again, variability in conductivity was observed between different streams, and between different locations on the same stream.

2.3.4 pH and alkalinity

The pH of the streams was usually between 7 and 8, with little upstream-downstream difference. At the pH encountered in the rivers, most alkalinity was bicarbonate. The Yure system was consistently lower in alkalinity than the other rivers.

2.3.5 Suspended Solids

Increased suspended solids occurred at the beginning and end of the wet season with peak concentration recorded in the Humuya at El Cajón (3020 mg/l) and just above the Sulaco confluence (5320 mg/l). The maximum daily loading at El Cajón was 286,000 tonnes/day in September 1980. The record flood of May 1982 certainly exceeded this value. Most of the sediment loading occurs from May to October. Our estimate of 3.7 million tonnes is well within the MC 1977 estimate of 1-8 million tonnes per year. The R. Yure carried relatively low sediment loads. The importance of single storm events is evidenced by our August 6, 1980 estimate where 55% of the expected annual loading occurred in a single day! In the 43 km that has formed the Humuya branch of the new reservoir the suspended load of the stream increased by 50 to 100%. The organic content of the suspended sediment ranged from as low as 10% (wet season) to as high as 70% in the dry season. Because of the importance of phosphorus to the fertility of aquatic and terrestrial environments considerable attention is given to this element in the report (see 6.2.2).

2.3.6 Phosphorus

Total phosphorus (TP) and soluble reactive phosphorus (SRP; phosphate phosphorus) were measured in these studies (see 6.2.7 for further explanation). At the dam site, TP peaked at the beginning of the wet season all three years of the study, with some variability between years. The SRP was less variable since it is less dependent upon particulate transport, but also tended to peak at the beginning of the wet season. After initial flushing from the watershed, growth of terrestrial vegetation takes a steadily increasing amount of P from the ground water, and the range of SRP, as a mean percentage of the TP was quite broad. Variations between the downstream stations may be related to waste discharge and land fertilization. Observed trends of TP as related to dischare are specific to individual river systems. In general, higher TP levels were associated with higher discharge in the R. Humuya, whereas lower TP levels were found at high discharge in the clearer R. Yure.

2.3.7 Nitrogen

Nitrogen may well be the most important single nutrient in the new reservoir. That appreciable quantities of nitrogen enter the stream systems via rain is evidenced by the consistently higher wet season concentrations found at all stations. Some of the nitrous oxides released in burning are returned by precipitation. Concentrations from the R. Chiquito were the highest measured in the sampling program. R. Yure did not show the dilution effect that it did for total phosphorus. Ammonia nitrogen concentrations proved to be much lower than nitrate nitrogen and differed between wet and dry seasons. R. Chiquito had high ammonia levels which probably reflect waste discharge. Ammonia analysis is particularly subject to artifacts of contamination and no distinct seasonal patterns were obvious from the data.

2.3.8 Nitrogen to phosphorus ratios

The ratio of N:P should be in the range about 7:1 by weight to meet plant requirements. Because the average N:P ratios from the three main tributaries are all below 7 (Sulaco 2.5, Humuya 0.9, R. Chiquito 4.3, and the Yure 2.2), it appears likely that the reservoir will have an N:P ratio below 7, and thus algal growth will tend to be more limited by nitrogen than phosphorus.

2.3.9 Iron, Silica and Cations

Iron is extremely reactive and is quite insoluble in its oxidized ferric state. Iron concentration correlated well with suspended solids indicating that most of the iron load was associated with input as particulate material. Wet season iron loads were always higher than dry season and correlated positively with discharge.

Silica as silicon dioxide was measured because of its importance to diatom growth. Although the Humuya at Comayagua had higher dry season concentration, there was little seasonal variation in the Sulaco at Victoria. In general, cation concentrations increased with low flow as the result of a greater relative contribution by ground water.

2.3.10 Conclusions on General Water Chemistry

In general the waters of the system are dominated by calcium bicarbonate derived from watershed soils. The concentration of substances related to erosion (phosphorus and iron) increase with the increased wet season flow of the rivers, while those associated with groundwater decline in concentration as surface flows increase. As the vegetation growth accelerates in the wet season it reduces the terrestrial nutrient loss to the aquatic system by recycling while biological factors in the streams further modify the chemical composition of the discharge. The differences identified for the major rivers will influence the fertility of those portions of the reservoir they enter. Further, if their wash load of sediment is high they will greatly reduce the light penetration at the upper reaches of the reservoir unless their density is sufficent to underflow the reservoir; see section 9.2.2).

2.4 THE LAKE STUDIES

2.4.1 Lago de Yojoa

Lago de Yojoa and Lago Yure provided limnological training, experience with the flora and fauna, and valuable insight into the probable functioning of the new El Cajón reservoir. Further, the past and future PIP studies will greatly assist in the development of a rational management program. Lago de Yojoa, like the rivers, is strongly dominated by wet season-dry season regimes. Unlike L. Yure, which has not had the time or the morphometry to develop higher aquatic plants, dense growths of plants were found in L. de Yojoa along the eastern shore. A flooded forested area at the southern end of the lake is now infested with water hyacinth (*Eichhornia*). The limnological chacteristics of L. de Yojoa include complete mixing in November to December with another possible period of mixing during July and August depending upon the frequency and magnitude of storms during this period. Lago de Yojoa can stratify during any season with a maximum temperature difference between surface and bottom water of about 5 C. Seasonal transparency changes are not great but maximum transparency occurs in November, following stratification. The pH of L. de Yojoa averages about 7.4 in the surface waters and about 6.9 in the deeper hypolimnion. Alkalinity values usually range from 60-75 mg/l as calcium carbonate, with little difference between the epilimnion and hypolimnion. There is a general oxygen reduction with stratification and the bottom waters may become anoxic by the end of March. Wet season inflows of particulate materials increase TP and iron concentration during the wet season whereas depletion of inorganic nitrogen is evident in the epilimnion. Therefore, there is a tendency for the N:P ratio to decrease during the wet season. Silica appears to be very conservative and levels remain fairly constant throughout the year.

2.4.1.1 Primary Productivity: Measurable primary productivity (PPr) occurs to depths of 13-15 m, with a subsurface peak between 3 to 6 m, probably resulting from both clear water and high surface radiation (causing photoinhibition and thus decreased productivity at the water surface).

Higher PPr occurs during the dry season. There were however, peaks in both the wet and dry seasons corresponding to periods of mixing. Overall there was high seasonal and yearly variation in PPr.

2.4.2.2 Phytoplankton: A good deal of work remains to be done on taxonomy as there were many problems in species identification. Most of the forms referred to are identified only to genus.

The phytoplankton community in Lago de Yojoa is dominated by diatoms, bluegreen and green algae. Generally, diatoms were the most important early in the year. Colonial chlorophytes were the most abundant group, both in numbers and biomass, and exhibited little seasonal variation. Other groups within the chlorophyta were not typically abundant. The bluegreens were the most important group in terms of biomass, and on some sampling dates large blooms may have accounted for some anomolously high PPr measurements. It is important to note that none of the bluegreen species found in L. de Yojoa have been reported to fix molecular nitrogen.

As with the tropical phytoplankton, some problems of zooplankton identification occurred. Ten taxa were numerically important in the zooplankton community, with several other species represented inconsistently with low numbers and biomass. The most abundant genera observed over the 2 1/2 year period were 2 cladocerans, 2 copepods (1 cyclopod and 1 calanoid) and 2 rotifers. There was a tendency toward high zooplankton densities during the wet season although inconsistencies exist between species and years. Typically, during the wet season there would be a progression of dominant species. The order of species progression, as well as which species would become dominant, is, however, not predictable.

There was no clear relationship between PPr and zooplankton densities and production. Presumably this was related to the difficulty that zooplankton have in assimilating the often dominant bluegreen algae. Nevertheless, these algae ultimately enter the zooplankton food supply as detritus and they also may eventually contribute to fish production. The similarity of L. Yure makes it the most valuable comparison with L. El Cajón. Its low hypolimnetic oxygen concentration is certain to be duplicated on a much greater scale in the new reservoir because of its great depth.

2.4.2 Lago Yure

Lago Yure was formed in 1978 by diversion of the R. Yure in order to increase power generation from Cañaveral/Río Lindo hydroelectric system. The reservoir is a small, steep-sided, dendritic lake with three main branches and an annual rainfall of abut 3 m. Although draining originally forested land, much of this vegetation is now being cleared for cultivation. The surface of L. Yure is about 2.5 months. Macrophyte growth is restricted by the steep shoreline of the lake which provides a very narrow littoral zone. Beds of _Chara_ are the dominant macrophyte with some clumps of the grass _Paspalum_. Lago Yure is a monomictic lake mixing completely in December and January.

Surface temperatures varied from 20 C in December/January to 26 C in June with bottom temperatures remaining nearly constant at about 17 C. The main tributary, R. Yure, typically flowed along the lower part of the epilimnion during stratified periods.

Light penetration was extremely variable at different depths and during different seasons. Clearest water typically occurred in December to April with more turbidity in the wet season brought in by streams. The zone of photosynthesis in L. Yure was very short during much of the year. Analysis indicates the importance of inorganic particles in the wet season. The percentage of ash-free dry weight (a measure of organic content) sedimented particles collected at 50 m from the dam amounted to 20% in the wet season and 38-60 % in the dry season. Sediments examined from different branches of the lake showed higher organic content from Q. del Cerro relative to other streams.

Surface conductivity ranged from 45 to 55 μmho/cm at the surface and increased to 65 umho/cm near the bottom due to decomposition of sedimenting material. Alkalinity values showed little variation but decreased between June and October of 1981 to about 7 mg/l calcium carbonate. Values of pH ranged from 6.4 to 8.5. The higher values corresponded to periods of higher algal growth with carbon dioxide removal during photosynthesis.

Distribution of oxygen limited the zone inhabitable by fish and invertebrates in L. Yure. Following stratification, the lake was essentially anoxic below 7 - 10 m. Only at year-end after mixing do the deep waters become oxygenated. Photosynthesis was restricted by light penetration to approximately the same 7 - 10 meter zone and contributed significantly to the oxygen concentration there. Patterns of seasonal oxygen distribution were similar during the three study years, although winter circulation was incomplete in 1981 leaving low, 3 mg/l levels below 16 m. Some underflow of oxygen replenishment apparently occurred in late August of 1980 from tributary streams.

Phosphorus (P) is important to lake productivity and levels in the surface waters of Lago Yure were always below 10 μg/l. Inflow waters were consistently higher than outflow indicating stripping of P in the reservoir by phytoplankton and sedimentation. Although deep water phosphorus levels remained generally low, in 1982 they increased to 39 μg/l. The low concentrations of P in L. Yure may reflect loss during land clearing, generally phosphorus-poor soils of the basin, and efficient recycling of P by phytoplankton reducing the amount sedimented to the bottom.

Nitrate nitrogen and ammonia were inversely correlated in L. Yure. A seasonal pattern of hypolimnetic ammonia buildup during stratification is evident. January mixing reduced ammonia in the entire water column presumably by oxidation to nitrate (nitrification). Nitrate levels showed regular depletion by phytoplankton at the surface. Stream loading of nitrate was high during the wet season. As for phosphorus, outflow values were depleted in nitrogen when compared with inflows.

Lago Yure surface waters showed an inorganic nitrogen to total phosphorus ratio of 8.9 compared to the three tributary inputs of 15.2, 12.6, and 8.1. Iron levels followed the classic inverse relationship to oxygen with higher concentrations in the anaerobic hypolimnion and lower levels in the well-oxygenated epilimnion. Silica was higher in the surface than in the deep water but showed no clear seasonal pattern. Significant concentrations of hydrogen sulfide were present in the anoxic hypolimnion, reaching over 900 mg/l at 15 m to the lake bottom in September 1982. The four major cations; magnesium, calcium, sodium and potassium, were uniformly distributed down the water column and showed no pattern of biological depletion. Synoptic studies revealed considerable variation within the reservoir with the patterns being related to the behavior of different tributary inflows which may underflow or move along the thermocline region between the epilimnion and hypolimnion.

Some nutrient budgets were estimated from the data on L. Yure for nitrogen, phosphorus and iron by multiplying mean daily discharge by concentration. This budget is only a first approximation and insufficient sampling of streams probably explains why a higher phosphorus discharge than input was measured.

Most of the primary productivity in L. Yure occurred in the upper 3 meters although net productivity often occurred to 6 meters. The overall seasonal trend was for higher productivity from March to June, when light levels were highest and abiotic (suspended sediment) turbidity lowest. In general low light transmission was a major limiting factor for algal growth in the lake. Seasonal patterns of productivity were similar from year to year but the dry season peak in May 1982 was particularly high. After July of the same year productivity decreased rapidly. The general increase from 1980 to 1982 may represent the early phase of increasing reservoir fertility before a plateau and eventual decline occurs. Synoptic studies showed only moderate differences between the three different stations sampled.

A series of bioassay experiments indicated inhibition of PPr by river waters Although further study is needed it is possible that sediment actually contained inhibiting substances or removed phosphorus from solution by adsorption. In nutrient experiments both P and Fe stimulated algal growth. Micronutrients did not stimulate growth unless combined with N and P, nor did nitrogen unless combined with P.

The Chlorophyta (green algae) dominated the L. Yure phytoplankton while diatoms and bluegreens were relatively rare. *Cosmarium* was occasionally quite abundant. These contributed significantly to dry season productivity.

Some striking changes occurred in the L. Yure zooplankton population during the study period. Before May 1982 one cladoceran (*Moina micrura*), one cyclopod copepod (*Tropocyclops prasinus*) and eight rotifers dominated the community. The rotifers fluctuated greatly throught the year with a peak density of 2.5 million individuals per square meter in May 1981. *Brachionus angularis* comprised more than 99% of this bloom. At the middle of 1982 the large cladoceran *Daphnia pulex* was first recorded in L. Yure, although the species was the dominant form in L. de Yojoa at the time. These reached 300,000 individuals per square meter at the beginning of July. This followed a drastic decline in rotifers from 1.3 million to 0.1 million per square meter between May and June 1981. The data suggest that *Daphnia* inhibited the recovery of the rotifer population. The other observations included a decline in the previously dominant *Moina* cladoceran which also failed to recover to pre-*Daphnia* population levels. Vertical collections indicated that *Daphnia* stayed in the well-oxygenated surface waters while copepods remained in deeper water with reduced light and oxygen levels.

2.4.3 Synthesis

In the El Cajón reservoir the Sulaco branch will be more protected from major winds and will probably have a shallower thermocline than the more exposed Humuya branch. The behavior of tributary inflow will be particularly important since it will probably mix during cool, low sediment periods, underflow during colder high discharge periods and perhaps move as an intermediate plume through the middle depths of the reservoir for some distance at other times. The principal stratification will occur between 5 and 10 m and the expected thermal structure of L. El Cajón should provide for a 4 to 7 C degree differential between surface and bottom waters. With large amounts of terrestrial vegetation still in the basin and the extreme depth of the lake, it is almost certain that the reservoir will contain a very large and stable volume of anaerobic water. The hydrogen sulfide production may be great enough to cause problems at the dam and downstream for several years. Further, the warm dominant inflow of the

Humuya which is rarely below 20 C will provide for both a higher rate of decomposition and a higher level of thermal stability (resistance to mixing) which, to some degree, will be counteracted by the longer wind exposure, as compared to L. Yure. Shading from the steep canyon wall may reduce the daily solar heating. Of particular importance is the hypolimnetic discharge which removes colder water and nutrients from the lake and allows for a longer period of heating of the epilimnion. Hypolimnetic discharge removes the cooler nutrient-rich waters of the reservoir during periods of stratification. The discharge from L. El Cajón will be low in oxygen and may well contain appreciable concentrations of hydrogen sulfide.

Underflow bringing some oxygen to the deep waters of the El Cajón should occur in December and January. This volume of inflow is only 6% of the reservoir volume and will have a negligible effect on the mixing regime. During the wet season the temperatures of inflow should cause an interflow although the highest sediment loads may cause underflow at the upper reaches of the reservoir. At times a plug-flow may move right through the reservoir to the penstocks.

Surface cooling is expected to cause sufficient reduction in the density gradient to increase the mixed zone in L. El Cajón. Accompanied by strong (storm) winds this could conceivably mix the reservoir but complete mixing is not expected to occur. Because of the great depth, high temperatures of inflow, and limited wind exposure it is very doubtful that sufficient energy will be available to mix the lake all the way to the bottom. The depth of annual mixing will however, be extremely important with respect to annual primary productivity, accumulation of hydrogen sulfide, and the aerobic volume of water available as zooplankton and fish habitat. The large dead storage (33% of the reservoir volume) is expected to remain as a stagnant pool. Turbidity at or near the surface will tend to reduce the thickness of the epilimnion and cause warmer surface temperatures and higher evaporation.

The nutrient content of the productive surface waters of the reservoir will be strongly influenced by the content, mixing, or lack of mixing of stream inflows. If underflowing turbidity currents are a common occurrence, available nutrient input will be greatly reduced. The relatively low concentration of nitrate nitrogen in the Humuya, Sulaco and Yure rivers suggest that the lake will be more similar in nitrogen content to L. de Yojoa than to L. Yure. Phosphorus and nitrogen concentrations will exhibit the same seasonal trends of higher wet season input. If the N:P ratio of the tributaries is considered, the ratio is sufficiently low (less than 3) to suggest nitrogen limitation during at least a portion of the year. The cation ratios in L. El Cajón are likely to end up intermediate between Yure and Yojoa, although the arms of the reservoir may show sufficient differences to influence phytoplankton composition.

Primary productivity in the two comparative lakes is surprisingly similar but is to some degree dominated by abiotic turbidity restricting the euphotic zone during the wet season. Lago de Yojoa often has a photosynthetic profile about 4 m deeper than L. Yure. Unfortunately the depth of photosynthesis in L. El Cajón is likely to be more similar to the turbid L. Yure than to the more transparent and better wind-mixed L. de Yojoa. L. El Cajón expected to show a great deal of spatial heterogeneity between arms. Light limitation coupled with possible nitrogen deficiency in this solidly stratified system are likely to be the major limiting factors for algal growth.

Zooplankton populations are important to the well being of the fish stocks and are likely to evolve along the lines of L. Yure described in considerable detail in the report. It will be interesting to see if Daphnia pulex achieves dominance in one or two years in the El Cajón reservoir. The benthic population of insect larvae are not likely to do well if rapid drawdowns expose an already limited littoral zone. Those able to migrate with the water and those tolerant of low oxygen conditions are likely to dominate. The dragonfly larvae Idiataphe may form an important food for the bass population which is almost certain to rapidly establish itself in the reservoir.

Although terrestrial vegetation clearance has reduced the threat of Eichhornia infestation, the upper reaches of the reservoir remain likely sites of invasion. Particular attention should be directed towards detecting and eliminating any islands of infestation. Rooted higher aquatics can help stabilize shorelines, but will take 3-6 years to become established and will have limited success along the steep shorelines of the new reservoir. Mass wasting remains a serious threat and reforestation is essential to reduce the danger.

In conclusion, the spatial heterogeneity of the reservoir will be of special interest. The Humuya and Sulaco branches will be most similar since river valley morphology and water chemistry are similar. The Yure branch will have a relatively low suspended sediment load and a reduced abiotic turbidity providing for a thicker epilimnion and deeper euphotic zone. This suggests that the Yure will be the more productive branch although lower phosphorus loading may reduce its producivity. The relative behavior of the inflowing streams will be a dominant factor in establishing the effective fertility of the reservoir arms. L. El Cajón will be a very complex ecosystem and a carefully designed monitoring program will be necessary to understand it. The existing data base can already provide extremely valuable insights into its workings. Individual programs for vector, aquatic weed and fish management can be tailored to fit the individuality of the reservoir's separate arms. The system remains a remarkably interesting challenge for future investigation and management.

2. SUMARIO

2.1 INTRODUCTION

2.1.1 Trascendencia de las investigaciones.

Este estudio cubre una amplia área de muestreo del futuro embalse, asi como de los ríos y lagoS asociados desde 1979 hasta 1982. Particular atención fue otorgado al muestreo regulado del lago Yure y del lago de Yojoa para acrecentar el entendimiento del nuevo ambiente y entrenar biólogos hondureños en las investigaciones y manejo de limnología y de peces. Debido a la relevancia de los estudios en el lago Yure para el futuro embalse y el programa posterior al embalsamiento (PIP), el lago Yure fue muestreado, cada dos semanas después del primer año, con una peculiar atención en la dinámica de cadenas alimenticias. La calidad de agua fue monitorizado en 15 estaciones incluyendo 4 estaciones localizados debajo del sitio de la presa. La localización de los lugares es mostrado en la Fig. 4.1, así como dos estaciones fueron incluídas en cada uno de los tres principales ríos (Humuya, Sulaco y Yure). La estación de muestreo #9 en el sitio de la represa representó una integración de varios aflujos hacia el nuevo embalse de El Cajón y el muestreo de ésta estación fue la más frecuente. Una quebrada pequeña Q. El Cajón, el cual afluye justamente por debajo del sitio de la presa fue muestreada cada dos semanas durante el primer año del estudio.

Asi mismo, dos pequeños estudios fueron incluídos en el programa. El primero fue el proyecto de diversión y represado del río Tamalito (ver apéndice 6) y el segundo concierne a la descarga de sedimentos suspendidos del río Humuya (ver sección 6.2.6).

La productividad primaria fue medida en ambos lagos, Yure y Yojoa junto con el fitoplancton y zooplancton. Además de la larvas de insectos del río, los invertebrados bénticos del lago Yure fueron también muestreados, por cuanto estos organísmos son muy importantes para los peces. A lo largo de la cuenca, las poblaciones de peces fueron estudiados para determinar su distribución. Los muestreos frecuentes del lago Yure y del río Yure proporcionaron una documentación importante acerca de los cambios estacionales en ambos, reproducción y alimentación así como en el desarrollo de la pesca en el lago Yure. Los detalles de este extenso estudio de peces se incluirán en el segundo volumen como sección 11. Las recomendaciones para el PIP, no obstante han sido incluídos en este volumen (3.3).

2.2 METODOLOGIA

2.1.2 Metodologias físicoquímicas de muestreo.

Los mejores métodos disponibles para el muestreo y análisis fueron empleados. Muestras duplicadas fueron colectadas regularmente en los estudios fluvial y lacustre, una tercera muestra fue tomada para el análisis de sólidos suspendidos. Medidas in situ de conductividad, temperatura y oxígeno disuelto fueron tomados regularmente y el ph fue medido tan pronto fue posible luego de la colección de la muestra. Un medidor de corriente fue el proveedor de las medidas de flujo fluvial y la penetración lumínica fue medida por el disco de Secchi y un fotómetro sumergible. La alcalinidad, turbidez, sólidos suspendidos y fluorescencia fueron medidos tan pronto como fue posible posterior a la colección. El análisis de cationes fue ejecutado por un espectrómetro de absocción atómica en Davis de California; los otros análisis químicos fueron analizados como son descritos en el Standard Method (APHA 1975). Un periheliógrafo en Santa Cruz proporcionó una continua colección de la radiación solar.

2.2.3 Metodología biológica de muestreo.

La productividad primaria (fotosíntesis por algas) provee una integración biológica del ambiente físicoquímico y forma la base de las cadenas alimentícias del lago. El método del carbano 14 fue usado para medir directamente la productividad así como las bioensayos para análizar los factores nutritivos que afectan el crecimiento de las algas. La metodología estándar de oxígeno fue usado para determinar la demanda bioquímica de oxígeno (BOD). Las muestras de fitoplancton fueron colectadas a la vez en profundidades discretas e integradas a traves de la zona iluminada (ó eufótica). Un manual para el procedimiento y uso del microscópio invertido fue desarrollado (ver apéndice 5). La identificación previa del fitoplancton y el desarrollo de un manual de laboratorio fue realizado en Davis. Tiradas verticales de red fueron usadas para colectar el zooplancton y los invertebrados de ríos fueron muestreados siguiendo métodos estándar.

Los peces fueron colectados por electrochoque, redes provistas de flotadores en la parte superior y pesas en la inferior y en una serie de tamaños en las mallas de las redes. Redes de tiro y cargas exposivas fueron usadas en pocas ocaciones. Algunos de los peces más grandes fueron comparados de pescadores locales. Los peces fueron medidos, pesados e identificados. El contenido estomacal fue analizado y su volumen determinado. La condición del pez fue evaluada através de la acumulación de grasa en la tripa. Para algunas especies, el estado reprodivctivo fue también determinado. Las razones de crecimiento fueron estimados por marcado, análisis distributiva de tamaños del cohorte y el análisis de escamas. Las recomendaciones en el estudio de peces están en la sección 3.3 y en la sección 11 del volumen II.

2.3 Estudio de la calidad de agua fluvial.

2.3.1 Introducción.

El drenaje del Sulaco cubre el 56% del total unos 8320 kilómetros cuadrados del drenaje de la cuenca el cual incluye también los ríos Humuya y Yure. Un treinta y cinco porciento de los valles en forma de V del drenaje del Humuya tienen pendientes que son mayores del 40%. El Sulaco tiene aún mayor porcentaje de pendientes escarpados. El uso agrícola de corte y quema aparece atravéz de la cuenca y por debajo de la línea de 30 m.s.n.m., 38% del área estaba forestada. La limpieza del embalse probablemente ha ascendido cerce del 50% por ahora. El Valle de Sula por debajo de la represa de El Cajón está aproximadeamente 26% cultivado y un 46% como pastura o dejado en barbecho. Los valores medios de las estaciones seca (entre enero y abril) y lluviosa (entre junio y septiembre) ihan sido calculados para la mayoría de los parámetros de calidad de agua en un total de 18 estaciones.

Generalizaciones importantes de nuestros estudios indican que los ríos Humuya y Sulaco son bastante similares pero el río Yure difiere marcadamente por un flujo lento, turbidez, fósforo total, conductividad, alcalinidad y contenido de metales. El nitrógeno, sin embargo, difiere muy poco entre los tres ríos y eventualmente podrá ser un factor limitante en la fertilidad del nuevo embalse de El Cajón.

2.3.2 Temperatura fluviales

Típicamente las temperaturas fluviales se rezagan de la radiación solar y alcanza sur máximo entre abril y agosto. El rango anual varió entre diferentes ríos y localizaciones. Los niveles de exígeno fueron un poco bajos en la estación lluviosa que en la seca, pero fueron usualmente por encima del 90% de saturación.

2.3.3 Conductividad.

La conductividad, relacionado con iones disueltos, incrementó entre noviembre y abril y disminuyó entre mayo y septiembre. Esto refleja el gran percentaje del agua subterránea que entra al río durante la estación seca. Asi mismo, la variabilidad de la conductividad fue observada entre difrentes ríos y entre diferentes localizaciones en el mismo río.

2.3.4 ph y alcalinidad.

El ph de los ríos era usualmente entre 7 y 8, con pocas diferencias entre río arriba y río abajo. Acorde con los ph encontrados en los ríos, la mayoría de la alcalinidad era bicarbonato. El sistema del Yure fue consistentemente más bajo en alcalinidad que en otros ríos.

2.3.5 Sólidos suspendidos.

Un incremento en los sólidos suspendidos ocurrió al principio y término de la estación lluviosa con la concentración más alta registrado en el río Humuya en El Cajón (3020 mg/l) y justamente arriba de la confluencia del Sulaco (5320 mg/l). La carga diaria máxima en El Cajón fue 286,000 toneladas/día en septiembre de 1980. La inundación registrada en mayo de 1982 ciertamente excedieron este valor. La mayoría de la contribución de los sedimentos ocurre desde mayo hasta octubre. Nuestra estimación de 3.7 millones de toneladas está en concordancia con la estimación del Motor Columbus en 1977 de 1 a 8 millones de toneladas por año. El río Yure acarreó relativamente bajas contribuciones de sedimentos. La importancia de los eventos de una tormenta está fundamentado por nuestra estimación del 6 de agosto de 1980 donde el 55% de la contribución anual esperada ocurrió en un solo día! De los 4.3 km. que forma la rama del Humuya del nuevo embalse, la contribución de suspendidos fluviales incrementó del 50 a 100%. El contenido orgánico de los sedimentos suspendidos varía entre valores tan bajos como 10% (durante la estación lluviosa) hasta tan elevados como un 70%

en la estación seca. Debido a la importancia del fósforo en la fertilidad de ambientes acuáticos y terrestres, una considerable atención es acentuado en este elemento en el presente reporte (ver 6.2.2).

2.3.6 Fósforo.

El fósforo total (TP) y fósforo reactivo soluble (SRP; fosfato) fueron medidos en estos estudios (ver 6.2.7 para mayor explicación). En el lugar de la presa, el TP alcanzó el máximo valor al inicio de la estación lluviosa en todos los tres años del estudio, con cierta variabilidad entre años. El SRP fue menos variable pues este es menos dependiente sobre el transporte particulado, aún asi también tiende a alcanzar valores máximos durante el principio de la estación lluviosa. Después del lavado inicial de la cuenca, el crecimiento de la vegetación terrestre toma un incremento uniforme en la cantidad de fósforo de aguas subterráneas y el rango de SRP, como un porcentaje medio del TP, fue bastante amplio. Las variaciones entre las estaciones río abajo estaría relacionado con la descarga de desechos y fertilización terrestre. Las tendencias observadas de TP con relación a la descarga son específicas a los sistemas fluviales individuales. En general, los niveles elevados de TP fueron asociados con la descarga elevada del río Humuya, mientras que los niveles bajos de TP fueron encontrados con la descarga elevada del río más claro, el Yure.

2.3.7 Nitrógeno

El nitrógeno bien puede ser el único nutriente más importante en el nuevo embalse. Que apreciables cantidades de nitrógeno entren al sistema fluvial por vía de la lluvia es evidenciado por las concentraciones consistentemente más elevadas durante la estación lluviosa encontrados en todas las estaciones. Algunos de los óxidos nitrosos liberados en las quemas son regresados a través de la precipitación. Las concentraciones del R. Chiquito fueron los más altos medidos en el programa de muestreo. El R. Yure no muestra el efecto diluyente que mostró con el fósforo. Las concentraciones de amoníaco probaron ser mucho más bajas que los de nitrato y diferenciándose entre las estaciones lluviosa y seca. El R. Chiquito mostró altos niveles de amoníaco los cuales reflejan la descarga de desechos en el río. El análisis de amoníaco está sujeto particularmente a los artefactos de contaminación y patrones estacionales distintivos no fueron obvios en los datos.

2.3.8 La razón entre nitrogeno y fósforo

La razón entre N:P deb estar cerca de 7:1 basado en peso, para reunir los requerimientos de las plantas. Debido a que las razónes medias de N:P de los tres tributarios mayores están todos por debajo de 7 (Sulaco 2.3, Humuya 0.9, R. Chiquito 4.3 y el Yure 2.2) de tal modo parece posible que el embalse tendrá una razón de N:P por debajo de 7 y por lo tanto el crecimiento de algas tenderá a ser más limitado por nitrógeno que por fósforo.

2.3.9 Hierro, Silício y Cationes

El hierro es extremadamente reactivo y bastante insolubles en su estado férrico oxidado. Las concentraciones de hierro correlacionaron bien con la carga de sólidos suspendidos fluviales indicando que la mayoría de la contribución del hierro fue como material particulado. Las contribuciones del hieero durante la estación lluviosa fueron siempre más elevados que las de la estación seca y correlacionando positivamente con la descarga. El silício como dióxido de sílice fue medido debido a su importancia para el crecimiento de diatomeas. Aunque el Humuya en Comayagua tuvo concentraciones más elevadas durante la estación seca, hubo poca variación estacional en el Sulaco en Victoria. En general, las concentraciones de cationes incrementaron con el flujo lento como resultado de la mayor contribución relativa por el agua subterránea.

2.3.10 Conclusiones generales de la química de agua

En general, las aguas del sistema están dominados por el bicarbonato de calcio derivado de los suelos de la cuenca. La concentración de sustancias relacionadas con la erosión (fósforo y hierro) aumentan con el incremento del flujo fluvial durante la estación lluviosa mientras que aquellos asociados con el agua subterránea declinan la concentración a la vez que el flujo superficial aumenta. Asi como el crecimiento de la vegetación acelera en la estación lluviosa, éste reduce la pérdida de nutrientes terrestres hacia el sistema acuatico a través de recirculación y factores biológicos en los ríos que posterionmente modificarán la composición química de la descarga. Las diferencias identificados para cada uno de los ríos mayores influenciará la fertilidad de aquellas porciones del embalse en donde afluyan. Más adelante, si la carga de sedimentos arrastrados es alta, ello reducirá grandemente la penetración lumínica en los capas superiores del embalse a no ser que sus densidades sean suficientes como para subfluir en el embalse (ver sección 9.2.2).

2.4 ESTUDIOS DE LOS LAGOS

2.4.1 Lago de Yojoa.

El lago de Yojoa y lago Yure proveyeron entrenamiento limnológico, experiencia con la flora y fauna y una valiosa incursión hacia el funcionamiento probable del nuevo embalse de El Cajón. Además los estudios pasados y futuro PIP asistirán grandemente en el desarrollo de un programa de manejo racional. El lago de Yojoa, como los ríos es dominado fuertemente por los regímenes estacionales seco-lluvioso. A diferencia del lago Yure el cual no ha tenido tiempo o la morfología para dessarrollar plantas superiores acuáticas, crecimiento densos de plantas fueron encontradas en el L. de Yojoa a lo largo de sus costa este. Un área inundada forestada en el extremo sur del lago está ahora infestado con el jacinto de agua (Eichhornia). Una de las características limnológicas del lago de Yojoa incluye una mezcla completa entre noviembre y diciembre con otro posible período de mezcla durante julio y agosto dependiendo de la frecuencia y magnitad de las tormentas durante este período. El lago de Yojoa puede estratificarse durante cualquier estación con una diferencia en temperatura máxima entre las aguas superficiales y del fondo aproximadamente de 5o. Los cambios estacionales de trasparencia no son grandes pero la máxima transparencia ocurre en noviembre seguida por estratificación. El ph del lago de Yojoa promedia cerca de 7.4 en las aguas superficiales y cerca de 6.9 en el hipolimnion profundo. Los valores de alcalinidad usualmente varía entre 60-75 mg/l como carbonato de calcio, con pocas diferencias entre el epilimnion y hipolimnion. Hay una reducción general del oxígeno con presencia de estratificación y las aguas del fondo llegarían a ser anóxicas a finales de marzo. La afluencia de materiales particuladas en las estación lluviosa incrementa el TP y la concentración de hierro mientras que la extenuación del nitrógeno inorgánico es evidente en el epilimnion. Por lo tanto, hay una tendencia de la razón de N:P de reducir durante la estación lluviosa. El silíco parece ser muy conservador y los niveles permanecen bastante constantes a traves del año.

2.4.1.1 Productividad primaria: la productividad primaria medible (PPr) ocurre a profundidades de 13 - 15 m. con un pico subsuperficial entre 3 a 6 m. como resultado probablemente de ambas, el agua clara y elevada radiación superficial (causando fotoinhibición y por tanto disminución de la productividad en las aguas superficiales).

Elevados valores de PPr ocurre durante la estación seca. Sin embargo había picos en ambas estaciones lluviosa y seca correspondientes a los períodos de mezcla. En total hubo variación elevada estacional y anual en PPr.

2.4.2.2 Fitoplancton: Un trabajo considerable que da por hacerse en la taxonomía ya que hubieron muchas problemas en la identificación de especies. La mayoría de las formas referidas son identificadas solamente hasta género.

La comunidad del fitoplancton en el lago de Yojoa es dominada por diatomeas, algas verde azuladas y algas verdes. Generalmente las diatomeas fueron más importantes al principio del año. Clorofitas coloniales fueron el grupo más abundante, ambos en número y biomasa y exibieron pocas variaciones estacionales. Otros grupos dentro de las clorafitas no fueron tipicamente abundantes. Las algas verde azulades fueron el grupo más abundante en términos de biomasa y en algunas fechas de muestreo, grandes florecimientos podrían haber explicado algunas medidas anormalmente elevados de PPr. Esto es importante notar ninguna de las especies de algas verde azuladas encontradas en el L. de Yojoa han sido reportados que fijan nitrógeno molecular.

Asi como con el fitoplancton tropical algunos problemas con la identificación del zooplancton ocurrió. Diez taxas fueron numéricamente importantes en la comunidad del zooplancton, con varias otras especies representados inconsistentemente con bajos números y biomasas. El género más abundante observado en período de los 2 1/2 años fueron 2 cladóceras, 2 copépodos (1 ciclopoide y 1 calanoide) y 2 rotíferos. Hubo una tendencia hacia altas densidades de zooplancton durante la estación lluviosa aunque inconsistencias existen entre especies y años. Típicamente, durante la estación lluviosa podría haber una progresión de especies dominantes. El orden de la progresión de especies también como aquella especie que podría llegar a ser dominante no es obstante predicible.

No hay una relación clara entre el PPr y las densidades del zooplancton y producción. Supuestamente, esto estuvo relacionado con la dificultad que el zooplancton tiene al asimilar las algas verde azulades tan frecuentemente abundantes. Sin embargo, finalmente estas algas entran al suplemento nutricional del zooplancton como detritus y ello también podría eventualmente contribuir a la producción de peces. La similaridad del L. Yure con el L. de El Cajón hace de éste la comparación más valiosa. Su concentración baja hipolimnética será ciertamente duplicada en una escala mucho más vasta en el nuevo embalse debido a su gran profundidad.

2.4.2 Lago Yure

El lago Yure fue formado en 1978 por la diversión del R. Yure en orden de incrementar la generación de poder para el sistema hidroeléctrico Cañaveral-Río Lindo. El embalse es un lago pequeño, de lados escarpados, de forma dendrítica con tres ramas principales y una precipitación anual cerca de 3 m. No obstante el terreno de la cuenca originalmente forestado, mucha de esta vegetación esta ahora siendo limpiada para el cultivo. La influencia superficial del L. Yure pasa a través de un canal hacia el lago de Yojoa. El tiempo de retención del lago Yure es cerca de 2.5 meses. El crecimiento de macrofítas está restringido por la línea de playa escarpada del lago el cual provee una zona litoral muy angosta. Densas masas de Chara constituyeron la macrofíta dominante con algunos grupos de la gramínea Paspalum. El lago Yure es un lago monomíctico mezclándose completamente entre diciembre y enero.

La temperatura superficial varía entre 20^{o}C entre diciembre y enero a 26^{o}C en junio y con temperaturas del fondo manteniendose aproximadamente constante de 17^{o}C. El tributario principal del río Yure, típicamente fluía a lo largo de la parte inferior del epilimnion durante los períodos estratificados.

La penetración de luz era extremadamente variable a diferentes profundidades e indiferente a las estaciones. Típicamente, el agua más clara sucedía entre diciembre y abril con mayor turbidez en la estación lluviosa acarreado por los ríos. La zona fotosintetizadora en L. Yure era de duración muy corta la major parte del año. El análisis indica la importancia de las particulas inorgánicas en la estación lluviosa. El porcentaje por peso de las particulas sedimentadoras libres de ceniza (como medida del contenido organico) colectado a 50 m. de la presa consistía del 20% en la estación lluviosa y de 38 a 60% en la estación seca. Los sedimentos examinados en las diferentes ramas del lago mostraron un elevado contenido orgánico de la Q. del Cerro relativo a las otras quebradas.

La conductividad superficial varió entre 45 a 55 µmho/cm en la superficie y aumentó hasta 65 umho/cm cerca del fondo causado por la descomposición del material sedimentado. Los valores de alcalinidad mostraron poca variación per disminuyó entre junio y octubre de 1981 cerce de 7 mg/l de carbonato de calcio.

Los valores de ph varían entre 6.4 a 8.5. Los valores más elevados correspondieron a períodos de elevado crecimiento de algas con la remoción de dióxido de carbono durante la fotosíntesis. La distribución del oxígeno limitó la zona habitable por peces e invertebrados en el L. Yure. Seguiendo a la estratificación, el lago era esencialmente anóxico por debajo de 7 a 10m. Solamente después de la mezxla al término del año, las aguas profundas llegan a ser oxigenados. La fotosíntesis fue restringida por la penetración lumínica aproximadamente en la misma zona de 7a 10 metros y contribuyó significativamente a la concetración de oxígeno en esta zona. Los patrones en la distribución estacional del oxígeno fueron similares durante los tres años del estudio, sin embargo, la circulación invernal fue incompleta en 1981 dejando niveles bajos de 3 mg/l debajo de los 16 m. Algunos resuministros de oxígeno de algunos ríos tributarios a través de subflujos ocurrieron a fines de agosto de 1980.

El fósforo (P) es importante en la productividad del lago y sus niveles en las aguas superficiales del lago Yure fueron siempre por debajo de 10 µg/l. Las aguas que afluyen fueron mayores que las efluentes indicando una remoción del P en el embalse por el fitoplancton y sedimentación. Sin embargo los niveles de fósforo en las aguas subterráneas permanecen bajos pero en 1982 ellos aumentaron a 39 $\mu g/l$. Las concentraciones bajas de P en L. Yure podría reflejar la pérdida durante el limpiado terrestre, por lo general en cuencas de suelos pobres en fósforo y una recirculación del P por el fitoplancton reducirán la cantidad sedimentado en el fondo.

El nitrato y amoníaco fueron inversamente correlacionados en el L. Yure. Un patrón estacional de incremento en amoníaco en toda la columna de agua se redujo durante la mezcla de enero supuestamente por la oxidación del nitrato (por nitrificación). Los niveles de nitrato mostraron un regular agotamiento por el fitoplancton en la superficie. Así como con el fósforo, los valores de nitrógeno en la efluencia fueron agotados cuando se comparan con la afluencia.

Las aguas superficiales del lago Yure mostraron una razón entre el nitrógeno inorgánico y fósforo total de 8.9 comparado con los valores de la entrada de los tres tributarios de 15.2, 12.6, y 8.1. Los niveles de hierro siguieron la clásica relación inversa con el oxígeno con las concetraciones más altas en el hipolimnion anaeróbico y los niveles bajos en el bien oxigenado epilimnion.

El silício fue más alto en la superficie que en las aguas profundas aunque no mostraron un patrón estacional claro. Concentraciones significativas del sulfuro de hidrógeno estuvieron presentes en el hipolimnion anóxico, alcanzando estos valores superiores de 900 mg/l desde los 15 m hasta el fondo del lago en septiembre de 1982. Los cuatro cationes más comunes de magnesio, calcio, sodio y potasio estuvieron distribuidos uniformemente a lo largo de la columna de agua y no mostraron patrones de agotamiento biológico. Los estudios sinópticos revelaron variación considerable dentro del embalse, siendo los patrones relacionados con el comportamiento de los diferentes aflujos de los tributarios; los cuales podrían moverse o subfluir a lo largo de la región del termoclino entre el epilimnion y hipolimnion.

Varios presupuestos fueron estimados con los datos del L. Yure para nitrógeno, fósforo y hierro al multiplicar la descarga media diaria por la concentración. Este presupuesto es solamente una aproximación preliminar y debido al muestreo insuficiente de los ríos probablemente explique porqúe la descarga más elevada en fósforo fue medido en vez de la carga.

La mayoría de la productividad primaria en el L. Yure ocurrió en los 3 metros superiores, sin embargo la productividad neta a menudo sucedía a los 6 metros. La tendencia integral estacional de productividad fue de valores más elevados desde marzo a junio, cuando las condiciones de niveles de luz fueron las más altos y la turbidez abítica (sedimentos suspendidos) las más bajas. En general, la baja transmisión de luz fue un factor limitante para el crecimiento de algas en el lago. Patrones estacionales de productividad fueron similares de año en año, sin embargo el valor máximo de la estación seca en may de 1982 fue particulamente elevada. Después de julio del mismo año, la productividad decreció rapidamente. El incremento general de ésta desde 1980 a 1982 podría representar una fase previa al incremento en la fertilidad del embalse antes de alcanzar una meseta y luego eventual declinación. Los estudios sinópticos mostraron solamente diferencias moderadas entre los tres diferentes estaciones muestreadas.

Una serie de bioensayos experimentales indicaron la inhibición del PPr por las aguas fluviales. No obstante, estudios adicionales son necesarios pues es posible que el sedimento realmente contenía sustancias inhibidoras o el fósforo fue removido de la solución por absorción. En experimentos con nutrientes, ambos el P y Fe estimularon el crecimiento de algas. Los micronutrientes no estimularon el crecimiento a no ser que fuesen combinados con N y P, el N no estimulaba a meno que estuviese combinada con P.

Las clorofitas (algas verdes) dominaron el fitoplancton del L. Yure mientras que las diatomeas y algas verde azulados fueron relativamente raras. *Cosmarium* fue ocacionalmente bastante abundante. Estos contribuyeron significativamente en la productividad de la estación seca.

Algunos cambios impresionantes ocurrieron en la población del zooplancton en el L. Yure durante el período del estudio. Antes de mayo de 1982, una cladócera (*Moina micrura*), un copépodo ciclopoide (*Tropocyclops prasinus*) y ocho rotíferos dominaron la comunidad. Los rotíferos fluctuaron grandemente a través del año con una densidad máxima de 2.5 millones de individuos por metro cúbico en mayo de 1981. *Brachionus angularis* constituyó más del 99% de este aflorecimiento. Al término de 1982, la gran cladócera *Daphnia pulex* fue encontrada por primera vez en L. Yure, aunque la especie ya era la forma dominante en L. de Yojoa en este tiempo. Estos alcanzaron 300,000 individuos por metro cuadrado al principio de julio de ese año. A esto siguió un declinamiento drástico en los rolíferos de 1.3 millones a 0.1 millon por metro cuadrado entre mayo y junio de 1981. Los datos sugieron que *Daphnia* inhibió la recuperación de la población de rotíferos. Las otras observaciones incluyen una disminución en la cladócera previamente dominante *Moina*, el cual también fracasó en recuperar los niveles de su población previos a la llegada de *Daphnia*. Colecciones verticales indicaron que *Daphnia* permanece en las aguas superficiales bien oxigenadas mientras los copépodos se mantienen en aguas más profundas con niveles reducidos de luz y oxígeno.

2.4.3 Síntesis

En el embalse de El Cajón, la rama del Sulaco será más protegido de fuertes vientos y probablemente tendrá un termoclino menos profundo que la rama más expuesta del Humuya. El comportamiento del afluyo fluvial será particularmente importante ya que probablemente se mezclará durante períodos friosy de bajos sedimentos, durante períodos elevados de descarga más fría con subfluyos y los cuales se muevan quizás como una vertiente intermedia a través de las profundidades medias del embalse y a veces por una distancia considerable. La estratificación principal ocurrirá entre 5 y 10 m. y la estructura térmica del L. El Cajón debe suministrar una diferencia de 4 a 7^{O}C entre las aguas superficiales y del fondo. Con grandes cantidades de vegetación terrestre aún en la cuenca y la profundidad extrema del lago, es casi seguro que el embalse contendrá un volumen de agua anaeróbica muy grande y estable. La producción de sulfuro de hidrógeno podrá ser suficientemente grande como para causar problemas en la presa y río abajo por varios años. Además la afluencia cálida dominante del Humuya el cual rara vez está por debajo de 20^{O}C proveerá a la vez de una proporción más alta de descomposición y un nivel más elevado de estabilidad térmica (resistente al mezcelado). Esto, en cierto grado será contraatacado por la exposición prolongada de vientos como se compararía al L. Yure y el ensombrecimiento por cañones de paredes escarpadas podría reducir el calentamiento solar diario. De particular atención e importancia es la descarga hipolimnética, el cual remueve agua más fria y con nutrientes del lago y permite períodos más prolongados de calentamiento del epilimnion. La descarga hipolimnética remueve las aguas más frias y ricas en nutrientes del embalse durante períodos de estratificación. La descarga de El Cajón será baja en oxígeno y bien contendría concentraciones apreciables de sulfuro de hidrógeno.

El subflujo que brinde algo de oxígeno a las aguas profundas de El Cajón deberá ocurrir entre diciembre y enero. Este volumen de afluencia es solamente un 6% del volumen del embalse y tendrá un efecto insignificante en el régimen de mezcla. Durante la estación lluviosa, la temperature de la afluencia debe causar un interflujo, no obstante, las cargas más elevadas de sedimentos podría causar un subflujo en las capas superiores del embalse. Por temporadas, el flujo de aguas más frías que las de la superficie podrían verterse más profundamente a través del embalse hacia la salida de agua de la presa.

El enfriamiento se espera que causa una reducción suficiente en la densidad de gradiente. Al mismo tiempo incrementará la zona de mezcla en el L. de El Cajón. Acompañado por fuertes vientos (o tormentas), este podría concevIblemente mezclar el embalse pero una mezcla completa no se espera que ocurra. Debido a su gran profundidad, altas temperaturas de afluencia y exposición limitada de vientos es muy dudoso que suficiente energía sea disponible para mezclar el lago en toda su extensión hasta el fondo. Sin embargo, la profundidad del mezclado anual será extremandamente importante con respecto a la productividad primaria anual, acumulación de sulfuro de hidrógeno y el volumen de agua aeróbica disponible como habitat para el zooplancton y peces. El gran almacenamiento inactivo (33% del volumen del embalse) se espera que permanezca como un estanque estacionario. La turbidez cerca o en la superficie tenderá a reducir el grosor del epilimnion y causará temperaturas superficiales más calidas y evaporación elevada.

El contenido de nutrientes en las aguas productivas superficiales del embalse serán fuertemente influenciado por el contenido, mezclado o ausencia de mezclado de los ríos afluyentes. Si las corrientes subfluyentes de turbidez son una ocurrencia común, la entrada de nutrientes disponible será enormemente reducido. La concentración relativamente baja de nitrato en los ríos Humuya, Sulaco y Yure sugiere que el lago será más semejante al L. de Yojoa en el contenido de nitrógeno que al L. Yure. Las concentraciones de fósforo y nitrógeno exhibirán las mismas tendencias estacionales de importanción elevada durante la estación lluviosa. Si consideramos la razón de N:P de los tributarios, la razón es suficientemente baja (menos de 3) para sugerir una limitación en nitrógeno, durante al menos parte del año. Las razones de cationes en L. El Cajón probablemente terminarán siendo intermedias entre Yure y Yojoa, aunque los brazos del embalse podrían mostrar diferencias suficientes como para influenciar la composición del fitoplancton.

La producción primaria comparados entre los lagos es sorprendentemente similar pero es en cierto grado dominado por la turbidez abiótica, restringiendo así la zona eufótica durante la estación lluviosa. El lago de Yojoa a menudo tiene un pérfil fotosintético cerca de 4 m. o sea más profunda que el L. Yure. Desafortunadamente, la profundidad fotosintética en el L. El Cajón es probablemente más parecido al turbio L. Yure que al L. del Yojoa más transparente y mejor mezclado por los vientos. El L. de El Cajón espera mostrar una gran heterogeneidad espacial entre los brazos. La limitación lumínica acompañada por la posible deficiencia del nitrógeno en este sistema solidamente estratificado serán probablemente los factores limitantes para el crecimiento de las algas.

Las poblaciones de zooplancton son importantes para el buen estado de las poblaciones de peces los cuales son posibles que evolucionen a lo largo de las líneas del L. Yure descritas en considerable detalle en el reporte. Sería interesante ver si Daphnia pulex consigue dominar en uno o dos años el embalse de El Cajón. Posiblemente la población béntica de larvas de insectos no estarán en buena situación si los rápidos desplazamientos exponen las limitadas zonas litorales. Aquellos capaces de migrar y tolerantes a condiciones limitadas de oxígeno posiblemente serán los que dominen. La larva de la libélula Idiataphe podría representar un alimento importante para la población del Bass, el cual es casi seguro se establecerá rapidamente en el embalse.

No obstante el peligro de infestación por Eichhornia, ha sido reducido por la limpieza de la vegetación terrestre, las capas superiores del embalse permanecen lugares propicios de invasión. Atención especial debe ser dirigido hacia la detección y eliminación de cualquier isla de infección. Plantas superiores enraizadas acuáticas pueden ayudar a estabilizar las líneas de playas pero tomará de 3 a 6 años para que lleguen a establecerse y estos tendrán a lo largo de las costas escarpadas del nuevo embalse de un éxito limitado. Masas de desechos continuan siendo un serio peligro y para reducir este peligro, la reforestación es esencial.

En conclusión, la heterogeneidad espacial del embalse será de especial interés. Los brazos del Humuya y Sulaco serán más semejantes debido a la morfología del vallee fluvial y su química de agua similar. El brazo del Yure tendrá una carga relativamente baja en sedimentos suspendidos y una reducción abiótica de la turbidez proveerá un epilimnion más profundo y ancho y por tanto una zona eufótica más profunda. Esto sugiere que el Yure será uno de los brazos más productivos, no obstante la carga reducida de fósforo podría disminuir su productividad. La conducta relativa de la afluencia fluvial será un factor dominante en el establecimiento de la fertilidad efectiva en los brazos del embalse. El L. El Cajón será un ecosistema muy complejo y para entenderlo será necesario un programa monitor cuidadosamente diseñado. Los datos básicos existentes pueden ya proveer vistas extremadamente valiosas hacia este logro. Los programas individuales para el manejo de vectores, plantas acuáticas y peces pueden ser diseñados para fijar los brazos del embalse según su individualidad. El sistema permanece un desafío excepcionalmente interesante para las futuras investigaciones y manejo.

3. RECOMMENDATIONS

3.1 INTRODUCTION

The El Cajón Limnology and Fisheries Program has established one of the most detailed pre-impoundment data bases that exist for hydroelectric projects in the tropics. A rare opportunity has thus been provided to undertake a Post-Impoundment Program (PIP) for an investigation of a large, new, man-made lake which can then be related in some detail to actual pre-impoundment conditions. Further, and most importantly, the (PIP) can provide immediate information for management decisions.

Long-term data sets are both rare and extraordinarily important for resolving environmental problems. This was recently underscored by an eminent limnologist, Dr. Likens (1983) in an address given to the Ecological Society of America on "A Priority for Ecological Research". Demonstrations of the value of long-term data sets for understanding lake systems were provided by Lund (1964) for silicon in the English Lake District and for the role of precipitation in influencing the primary productivity of two lakes by Goldman and de Amezaga (1984). The silicon studies spanned a period of sixteen years and precipitation -- primary productivity studies covered a period of twenty-four years. In recognition of the great importance of longer term investigations, the U.S. National Science Foundation has established a series of programs in North America for minimum periods of five years under their Ecosystems program. In Africa the Kanji Lake Station continues to develop lake management strategy from their post-impoundment program (Imevbore 1975). Correct interpretation of complex variables with considerable year-to-year variation can often only be made with uninterrupted data collection. It took over five years of uninterrupted data collection to show a statistically significant change in productivity and transparency in Lake Tahoe, California-Nevada (Goldman 1984).

The following recommendations are developed in four broad sections. These include:

1. Routine limnological monitoring program for the El Cajón reservoir and downstream from dam. (3.2)
2. Additional recommended limnological studies. (3.3)
3. Fisheries investigations. (3.4)
4. Interagency cooperation. (3.5)

3.2 ROUTINE LIMNOLOGICAL MONITORING PROGRAM FOR THE EL CAJÓN RESERVOIR AND OF THE RIO HUMUYA/ULÚA DOWNSTREAM FROM THE DAM SITE.

3.2.1 Index Station

An index station should be established immediately in Lago El Cajón, well below the confluence of the Humuya and Sulaco branches. This station should be sampled regularly at weekly or biweekly intervals. In order to ensure a fully representative series of sampling events, every effort should be made to sample the monitoring station at a fixed time frequency. In other words, routine primary production measurements (see below) should be made even if on the assigned day levels of solar radiation are low. Any sampling schedule changes should be limited to avoiding severe storms.

3.2.2 Monitoring Program

The routine monitoring program at the L. El Cajón index station should follow the pattern established for the study of L. Yure. Depths of sample collection, however, will have to be modified to account for the much greater depth of L. El Cajón. Further, operation of the dam may recommend sampling change to conform with some aspects of release and storage. It is suggested that the euphotic zone be sampled every 2-5 m, and thereafter every 10 m down to 60 m. Suggested sampling depths are 0, 2, 5, 7, 10, 15, 20, 30 m etc. The euphotic zone is unlikely to reach 40 meters in the new reservoir.Below this depth (approximately the depth of the turbine intakes), samples should be collected at 30 m intervals to the bottom. The maximum sampling depth for primary productivty should be about 3 times Secchi depth.

3.2.3 Alterations and Additions for Sampling L. El Cajón

A few alterations and additions to the basic sampling format used for L. Yure sampling format are suggested, as follows:

-- Hydrogen sulfide measurements should be done to the bottom of the water column.

-- Dissolved silica should be measured instead of total silica.

-- Dissolved iron should be measured in addition to or in place of total iron.

-- Water chemistry methodology should be converted to the micro-methods, as described in Appendix 9. Parallel runs of analyses should be included for calibration of all new versus old methods.

-- When measuring light profiles, an additional reading immediately below the surface should be taken to account for surface reflection.

-- Water samples analyzed for turbidity should also be analyzed for suspended solids concentration and % ash-free dry weight of particulate matter.

-- A new oxygen-temperature probe (with a longer cable) may be required for the instrument.

-- Chlorophyll analyses should be carried out routinely.

-- Establish or maintain the meteorology station with the pyrheliograph near the dam site.

3.2.4 Primary Productivity Measurements

Primary productivity measurements should continue to form an integral part of the monitoring program and the ^{14}C methodology should be used. Scintillation counting facilities are potentially available in Tegucigalpa. In the event of changing the method or instrument used for measuring ^{14}C incorporation, care should be taken to ensure its inter-calibration with the counting facilities at Davis used in the past studies of L. Yure and L. Yojoa.

If it is not possible to continue to use the ^{14}C methodology, then the oxygen method of primary production measurement should be employed. This is much less sensitive than the ^{14}C method, but should provide useful information. Parallel runs with ^{14}C and oxygen should be attempted. Full details on the O_2 method appear in Wetzel and Likens (1979). An incubation period of approximately 8 hours will probably be required in L. El Cajón although a 24-hour period from sundown to sundown could also be considered.

3.2.5 Nutrient Bioassays

A routine series of nutrient bioassays should be carried out using the L. El Cajón phytoplankton assemblage near the dam. It is suggested that these bioassays be carried out every month (4-6 weeks) during the first year of the reservoir's life, in order to assess any pattern of change in nutrient limitation through time. The bioassay methodology is described in section 5 of the report and should always include nitrogen and phosphorus additions, both separately and in combination. Initial spike concentrations should be calculated so as to increase ambient concentrations approximately four-fold. If inhibition of photosynthesis occurs, levels can be reduced.

3.2.6 Turbine Discharge Turbine discharge should be sampled at weekly intervals. All the routine water quality measurements should be made on these samples. In addition, samples should be analyzed for hydrogen-sulfide and biochemical oxygen demand.

At approximately 3-month (quarterly) intervals, a longitudinal series of down-stream samples should be collected, extending from the dam to Santa Rita, in order to determine the in-stream change in water quality discharged from El Cajón. Of special interest and importance will be the changes in oxygen and hydrogen-sulfide concentrations at various distances below the dam.

3.2.7 Hazard Survey of Reservoir and Tributaries

Efforts should be made to routinely sample at least one of the major rivers entering the El Cajón reservoir and to inspect all areas of the lake for severe shoreline erosion, mass wasting danger (landslides) and higher aquatic plant (e.g. Eichhornia) and disease vector (snail) invasions.

Regular reconnaissance of the reservoir should be made to identify unstable slopes capable of mass wasting landslides during storm events. These should then be carefully surveyed by ENEE geologists as they represent a serious potential standing wave hazard.

Since some of the snails present may be vectors for Schistosomiasis, surveys should monitor the snail populations.

River sampling surveys will enable investigation of the influence of the inflowing water quality and quantity on the reservoir's mixing regime and nutrient levels. River sampling could be "sub-contracted" out to someone living at Guacamaya, for example, and samples could be picked up monthly from the sample collector. Care should be taken to train the individual carefully. Provision for an electric or kerosene freezer would be the best way of sample preservation. If this is not possible, then chemical preservation (with H_2SO_4, $HgCl_2$ or chloroform) could be considered. A series of tests should be run to determine the effect of preservation method and storage on analytical results.

3.2.8 Meteorological Information

In order to provide the necessary meteorological background information for the limnological studies and a micrometeorological understanding of the reservoir environment, solar radiation, air temperature, relative humidity, and precipitation should be continuously measured at a location close to the index station. The existing meteorological station near the dam site would be the most convenient base for collection of this information. A recording wind gauge anemometer would be a valuable addition to the system to anticipate mixing events.

3.2.9 Bulk Precipitation Chemistry

Bulk precipitation (i.e., wet and dry fallout) chemistry should be routinely analyzed. A series of inexpensive plastic dry buckets could be placed around the area and changed routinely. Individual storms at the beginning of the wet season should be sampled because of the often higher nutrient loading via precipitation at that time. The effect of brush burning in Honduras as it influences reservoir fertility could be evaluated from this bulk collection. Precipitation pH should also be routinely measured and special care should be taken to standardize these measurements by cross calibration with other instruments and calibration with fresh, carefully prepared, buffer solutions. An extra (spare) pH electrode should always be on hand.

3.2.10 The Sampling Schedule

Taking into account the current strength of the laboratory personnel, a realistic prioritized sampling schedule should be developed immediately. Care must be taken in this program development to provide adequate time for sample analysis and data management. Although considerable experience has been gained by laboratory personnel, they may need some assistance in implementing the monitoring program outlined in these recommendations. Further, it would probably be desirable if ENEE consider hiring one or two additional personnel to get the post-impoundment program (PIP) underway. It might be possible to attract funds from the banks to help implement the PIP.

3.2.11 Data Storage, Retrieval, Analysis and Equipment

The importance of this aspect of the PIP can scarcely be overemphasized.

a) Data sheets will need to be adapted or revised for the greater depths encountered in the reservoir and new measurements to be made.

b) New programs will need to be developed for the HP calculator-plotter, or the existing ERA programs modified to handle the new data being collected.

c) It would be desirable if ENEE provided the limnology laboratory with a new, small computer with video screen, disc storage, and a person trained to input and retrieve data from the system. Use of existing ENEE computer facilities might be arranged with a telephone modum connection for data transfer, but a small personal-type computer with adequate storage and printer is now rapidly becoming an essential part a modern laboratory. This unit could supplement but not immediately replace the HP unit unless graphics were included.

d) Regardless of the availability at the Limnology Laboratory of computer facilities, ENEE is encouraged to begin obtaining the data and personnel necessary to combine hydrologic modeling with reservoir physical, chemical and biological conditions. This can be greatly facilitated by attention to 2.2.11 a) through d).

e) A moderately fast inboard motor launch equipped as a small floating laboratory would prove extremely valuable for the project. A power winch, cold storage, and filtration equipment would make synoptic work much easier and more reliable.

3.2.12 Annual Report

Development of an annual PIP report is an essential product of the monitoring program recommended above. Without the discipline of pulling the data together each year much of the value of the work will be lost for use in important reservoir management decisions. Some reporting should, of course, be immediate. If, for example, *Eichhornia* appears anywhere in the reservoir a boat should immediately be dispatched with herbicide to prevent a general invasion. If months are allowed to pass before action is taken the invasion may spread and be prohibitively expensive to control.

3.3 ADDITIONAL POST-IMPOUNDMENT PROGRAM LIMNOLOGICAL STUDIES OF THE EL CAJÓN RESERVOIR

3.3.1 Synoptic Sampling

Synoptic sampling is recommended to determine differences in fertility among the different arms of the reservoir. This involves sampling many stations over a relatively short time period to determine productivity, water chemistry and stratification throughout the reservoir. This approach is particularly valuable for pollution detection and control. A series of stations that can be reached during a single night should be selected or a three-day synoptic organized.

a) Primary Productivity: If a fast boat is available, samples should be collected at night, brought back and incubated all together at the index station Selection of a moonlit night will make navigation easier and samples should go in at dawn for 4-6 hour incubation. If a fast boat is not available, the personnel can be split into two groups and the synoptic run over a 3-day period.

Day 1: Index + Humuya (i.e., use index station as a control for different light levels and select about three depths to sample at each station).

Day 2: Index + Yure

Day 3: Index + Sulaco

Productivity samples can be filtered in the field and personnel can camp out to accomplish the synoptic.

Note: ^{14}C is injected into all samples just before their simultaneous incubation.

b) Water Chemistry. Standard water chemistry should be done at each station together with zooplankton taken from vertical net tows. Synoptic samples from different depths in the euphotic zone can be combined (pooled) to reduce analytical time.

3.3.2 Profiles of Stratification

Longitudinal profiles of temperature, oxygen, conductivity and suspended sediments (vertical suspensoid profiles) along, e.g., Humuya branch at beginning and end of the wet season would be valuable (see also 3.2.6 below).

3.3.3 Bioassays with River Water and Dam Effluent

River water and dam discharge can be assayed in ^{14}C-cultures by addition to surface, mid-reservoir water taken near the dam. This will determine the effective fertility of tributaries and indicate nutrient discharge from the system. Actual assays can be made with ^{14}C uptake, chlorophyll measurement, or phytoplankton cell counts. The ^{14}C assay is fastest and the most sensitive.

3.3.4 Nutrient Budgets

Future modeling of the new reservoir will require the kinds of data and sampling effort indicated in Appendix 7.

3.3.5 Sonar Transect

A delta will begin to encroach from the major tributaries into the reservoir as soon as the first flood flows arrive. A regular, annual sonar transect along the main arms will keep track of its progress towards the dam and the loss of live storage. Care must be taken to know the exact elevation of the reservoir surface during this annual transect. The transects should be done at the same time each year and perhaps be selected by reservoir water elevation during the early part of the dry season. A date when inflow is almost equal to discharge would be ideal.

3.3.6 Investigation of light limitation for phytoplankton primary productivty

The euphotic zone will probably be less than about 3 X the Secchi depth. Transparency transects along the length of the reservoir can prove useful in determining the productive volume of the reservoir and can identify the extent of light limitation in the more turbid portions of the reservoir. Since this phenomenon is highly correlated with behavior of turbid inflows, vertical profiles of sediment-bearing plumes can prove important. Depth of the plumes may be apparent from conductivity-temperature profiles.

3.3.7 Coliform Bacterial Analyses

A program for a longitudinal sampling transect down the Humuya for coliform bacterial analyses should be conducted during periods of low flow. Involvement of the Public Health Agency (Salud Pública) in this work is strongly recommended. Drinking water supplies could also be checked for the local inhabitants.

3.3.8 Stratification and Water Chemistry

Compare the limnology of cleared and uncleared areas of the reservoir for stratification and water chemistry. Particular attention should be directed towards oxygen and hydrogen sulfide profiles down the water column.

3.4 FISHERIES

3.4.1 Sampling the Reservoir

Beginning in early 1985 gill net sets of standard length and mesh should be fished at regular times in different parts of the lake. Since the lake's area is large relative to that of L. Yure and since catch per unit effort was low in the latter lake, a number of additional graded fleets of multifilament gill nets should be fabricated. Sampling should initially be concentrated on those areas of the shore-line where the slope is shallowest and those areas near the inflowing tributaries. As the lake fishery becomes more productive, sampling should include a more representative cross-section of habitats. The Yure branch and at least one of the Humuya and Sulaco branches should be selected. From the very onset of this program a major effort should be made to standardize gear and fishing hours as well as analysis and reporting.

Gill net set should initially be made at a variety of depths within the suggested zone. After these trials the zone with the higher catches per unit effort can be selected. Once selected these locations could be marked and fished at the same time each year with the same equipment as an index of abundance. Some gill net sets should be angled down perpendicular to the shore and fished as deep as oxygen is present. Experiments should be conducted with various fish traps to determine their utility.

Routine echo-sounding transects of the lake should be carried out in order to determine the development of any pelagic fish populations and to locate the most snag-free areas for gill net sets. Night echo location may be required to locate schools of fish migrating off shore at night.

If pelagic populations do develop, consideration should be given to obtaining a small mid-water trawl in order to carry out open water sampling. Alternatively open water (surface/mid-depth) gill net sets could be made in an effort to sample these fish.

3.4.2 Species of Economic Importance

Diets and reproductive condition should be analyzed for all (or a subsample of) the fish taken during the experimental fishing. Particular attention should be given to the following species, in view of their potential importance, either as a food fish for humans or as a component of the trophic network of the reservoir fish community: *Cichlasoma motaguense*, *C. managuense*, *C. maculicauda*, *C. spilurum*, *Rhamdia* spp., *Astyanax fasciatus*, *Brycon guatemalensis*, *Melaniris guatemalensis*, and the introduced species *Ictalurus* (bullhead), *Sarotheroden* (Tilapia) and *Micropterus* (black bass). These three introduced species are already present in the Humuya and/or Yure rivers. Their development in the new reservoir should be closely monitored. Populations of *Melaniris* should be sampled intensively, in view of their potential importance as an open-water forage fish. Some form of census by trawling or echo sounding will probably be necessary to adequately sample these fish.

3.4.3 Growth Rates of Fish

Growth rates of the cichlid species and of the *Rhamdia* species should be investigated using the methods described in sections 5 and 11. Initial efforts should concentrate on determining when growth checks/rings are laid down on scales, otoliths, and vertebrae. For this study a regular series of samples from throughout the year is required. Comparisons of growth rates should be made with those species studied in L. Yure and the R. Yure. The feasibility of continuing to use the cohort method of growth rate estimation should be investigated and a decision made as to its continuance (see Section 11.5).

3.4.4 Diet and Food Chain Studies

A comparison of the diets, distribution and reproductive success of the two cichlid species, C. motaguense and C. managuense should be made. These ecologically similar fish may be important as a food fish.

The fish food supply should be investigated through a series of zooplankton and benthos collections. Emergence nets may be useful for aquatic insects. Zooplankton species composition and its relationship to the developing fish community should be examined. Attention should focus on any marked changes in size, dominant species, and stomach contents of fish. Comparison of fish diet can be made between cleared and uncleared areas of the reservoir.

In order to further examine the interactions between fish and zooplankton, a series of laboratory feeding experiments should be started, concentrating initially on Astyanax and Melaniris.

3.4.5 Sampling Down-Stream Fish

The area immediately down-stream from the dam should be regularly sampled, especially for species such as Pomadasys and Centropomus. It would be valuable to compare fecundity of reservoir and river-caught fish (compare with the studies carried out on the Yure system). It might also prove useful to compare dry weights of eggs in these two populations and seasonal variation in this parameter. The breeding seasonality of major species already listed (3.4.2) should be compared with river-based data, specifically to see if lake reproduction is more continuous.

3.4.6 Sampling and Managing the Reservoir Fisheries

On the basis of initial investigations of reservoir fishery and data from existing river and L. Yure studies, the breeding seasons and the main spawning areas in the new reservoir should be determined.

Studies should be continued (sample 2+ years) in L. Yure to further document species shifts and development of the fish populations there.

No fish introductions should be considered for at least 5-6 years. The three exotic species present in the area (Micropterus, Ictalurus, and Sarotherodon) will almost certainly colonize the reservoir. The introduction of the cichlid C. urophthalmus should be considered later if it is not already present in the lake, since its main food (in L. de Yojoa) is snails -- including the genus Biomphalaria, which may be a potential vector for schistosomiasis.

The pelagic "niche" will be especially important in L. El Cajon, since the lake will have a very limited littoral zone. Effort should be made to determine if any of the native species are occupying this niche. If not, other Central American species might be considered for introduction (see Section 11.3).

Attempts should be made to determine the amount of time spent fishing by people living close to the reservoir and their success per unit effort. This creel census can be accomplished by sending groups into the field to interview people and to accompany them fishing. When fishermen are encountered on the lake, they can be questioned with a standard interview sheet by biologists. Later, fish tagging may improve population estimates.

Hook and line, trapping, and gill-net fishing in the reservoir should be allowed but mesh sizes should be controlled so that juvenile fish are protected. Once spawning areas are located, it may be necessary to close some of these areas to fishing at certain times.

3.4.7 Commercial and Sports Fisheries Development

If a commercial food and/or sports fishery is to develop in L. El Cajón, the data set developed from the studies indicated (3.4.1 to 3.4.6) is essential. The existence of cheap electricity from the dam would make a small freezing or icing plant possible if the fish population reaches levels adequate to sustain a steady harvest of significant commerical weight and value. A public relations program with posters informing fishermen of reward for tag returns, etc., can be developed to educate the local fishermen about regulation and management approaches as part of the laboratory's ongoing program.

After sufficient information is obtained on the spawning season and spawning locations, simple reservoir fisheries regulations should be developed to protect important spawning fish and speed the development of a viable fishery. An educational program would be helpful and a fisheries game warden will be required to enforce these regulations.

It should be possible and desirable to develop an experimental crocodile or cayman ranch adjacent to the reservoir. These ancient reptiles are now an endangered species and will probably only survive if protected in sanctuaries or farmed commercially. In Africa and New Guinea, ranching crocodiles for their extremely valuable hides has become an important industry. Alligator farming has long been profitable in the U.S. The farms also have the added economic benefit of being tourist atractions. The heads and guts of fish taken from the reservoir and undesirable species could be used to reduce the feeding costs. A very small pilot project could be started with one or two pair of animals captured from the reservoir. The enclosure could be set up near the dam or laboratory and could be managed by an interested zoologist-herpetologist from the existing laboratory staff or from the University. Without such an effort, the animals trapped behind the dam will probably be exterminated by poachers in a very short time. The World Wildlife Fund might be interested in supporting this venture. An experienced consultant in crocodile or alligator farming would obviously be very helpful in starting this project.

3.5 INTER-INSTITUTIONAL COOPERATION ON THE POST IMPOUNDMENT PROGRAM

1) Every effort should be made to develop studies in cooperation with COHDEFOR. For example, a series of studies on runoff water chemistry and sediment load presently being carried out in the L. Yure watershed could be

extended to the L. El Cajón watershed. Bioassay experiments with runoff of water and sediments could be included with those described in 3.1.

2) Choose and study intensively two stream watersheds, one forested, one not, to examine and compare fluctuation in sediment and nutrient yield. This project would benefit greatly from active participation by COHDEFOR.

3) Collaboration with DIGERENARE (Dirección General de Recursos Naturales Renovables) in development of reservoir management programs, especially the fisheries aspects, remains a desirable goal. The same applies to Salud Publica and vector control.

4) Develop ongoing programs with the Universidad Nacional Autónoma de Honduras whereby students do internships at the laboratory to carry out small research projects. This would be very beneficial and will provide "hands-on" experience for the next generation of biologists.

5) Initiate a regular field course in limnology at the laboratory for students. This course does not necessarily need to be taught by laboratory personnel (i.e., University people can take charge), but will tend to foster better cooperation with the academic institution. The Organization of Tropical Studies would almost certainly participate in a tropical limnology course.

6) Keep up the involvement of the limnology laboratory in other water-related projects done by ENEE. This will provide an important return for their investment in the PIP.

7) Consider buying an atomic absorption analyzer for metal analyses. This would be very useful for the project and could take in samples on a commercial basis to help pay for its cost.

8) Put together a written presentation of El Cajón PIP for publicizing the work to ENEE and other agencies. An illustrated pamphlet of approximately 20 pages giving a summary of projects carried out and type of work to be done in the future would be a valuable contribution to public awareness of the multi-

disciplinary nature of El Cajón programs and the facilities available for water resource-related work in Honduras.

3. RECOMENDACIONES

3.1 INTRODUCCION

El programa de limnología y pesca de El Cajón ha establecido uno de los datos básicos previos al embalsamiento más detallados que existe para los proyectos hidroeléctrico en los trópicos. Una oportunidad excepcional ha sido provista al emprender un programa posterior al embalsamiento (PIP) para la investigación de un nuevo y enorme lago hecho por el hombre, el cual puede ser relacionado luego en cierto detalle a las condiciones actuales previas al embalsamiento. Más adelante y mucho más importante, es que el PIP puede proveer información inmediata para las decisiones de manejo.

Grupos de datos a largo plazo son a la vez raros y extraordinariamente importantes para resolver los problemas ambientales. Este fue recientemente subrayado por un eminente limnólogo Dr. Likens (1982) en una alocución al Ecological Society of America como "Una prioridad para la investigación ecológica." La ilustración del valor de grupos de datos a largo plazo para la comprensión de sistemas lacustres fue provista por Lund (1964) para el silício en el distrito de los lagos ingleses y el papel de la precipitación que influye la productividad de dos lagos por Goldman y de Amezaga (1984). Los estudios de silício fue en un lapso de dieciseis años y el de precipitación cuyos estudios de productividad primaria abarcaron un período de veinticuatro años. En el reconociemínto de la inmensa importancia de investigaciones a largo plazo, la Fundación Nacional para la Ciencia estadounidense ha establecido unas series de programas en Estados Unidos por un período mínimo de cinco años bajo su programa de ecosistemas. En Africa, la estación del lago Kainji continua para desarrollar la estrategia en el manejo del lago de su programa posterior a su embalsamiento (Imevbore, 1975). La correcta interpretación de variables complejas con variaciones considerables de año en año puede a menudo ser realizado solamente con la colección de datos ininterrumpida. Tomó más de cinco años de colección ininterrumpida de datos para mostrar un cambio estatísticamente significativo en la productividad y transparencia del Lago Tahoe entre California y Nevada (Goldman, 1984).

Las siguientes recomendaciones están divididas en cuatro secciones extensas. Ellos incluyen:

1. Un programa monitor limnológico de rutina para el embalse de El Cajón y río abajo de la presa (3.2).
2. Estudios limnológicos adicionales recomendados (3.3).
3. Investigaciones de los peces (3.4).
4. Cooperación inter-institucional (3.5).

3.2 PROGRAMA MONITOR LIMNOLOGICO DE RUTINA PARA EL EMBALSE DE EL CAJON Y AGUAS ABAJO DEL RIO HUMUYA Y ULUA DESDE EL SITIO DE LA PRESA.

3.2.1 Estacion indice.

Una estación índice debe ser establecido inmediatamente en el Lago El Cajón, debajo de las ramas del Humuya y Sulaco. Esta estación debe ser muestreado regularmente a intervalos semanales o de dos semanas. A fin de asegurar una serie completa representativa de eventos de muestreo, cada esfuerzo debe ser ejecutado en la estación índice muestreando a frecuencias temporales precisas. En otras palabras, medidas rutinarias de producción primaria (ver abajo) deben ser realizado aún si en el día asignado los niveles de radiación son bajos. Cualquier cambio en el horario de muestreo debe ser reducido para evitar coincidir con tormentas severas.

3.2.2 Programa Monitor.

El programa monitor rutinario en la estación índice del lago El Cajón debe seguir el patrón establecido por el estudio del L. Yure. No obstante, la colección de muestras por profundidades tendrá que ser modificado tomando en cuenta la mayor profundiddad del L. El Cajón. Además, las operaciones de la presa podría recomendar cambios en el muestreo para amoldarse con algunos aspectos de liberación y depósito. Se sugiere que la zona eufótica se muestree cada 2 a 5 m. y luego cada 10 m. hasta los 60 m. Profundidades de muestreo sugeridas son 0, 2, 5, 7, 10, 15, 20, 30 m., etc. La zona eufótica es improbable que llegue a los 40 metros en el nuevo embalse. Por debajo de esta profundidad (aproximadamente al nivel de la profundidad de inyección a las turbinas), las muestras deben ser colectadas a intervalos de 30 m. hasta llegar al fondo. La profundidad máxima de muestreo para la productividad primaria debe ser más o menos 3 veces la profundidad del Secchi.

3.2.3 Alteraciones y adiciones al muestreo del L. El Cajon.

Unas pocas alteraciones y adiciones al formato básico de muestreo usado para el esquema de muestreo del L. Yure son sugeridas como sigue:

- Medidas de sulfuro de hidrógeno deben ser realizados hasta el fondo de la columna de agua.
- El silício disuelto debe ser medido en sustitución del silício total.
- Hierro disuelto debe ser medido en conjunto o en vez del hierro total.
- La metodología de la química de agua debe ser convertidos a micrométodos, como se ha descrito en el apéndice #9. Series paralelas de los análisis deben ser incluídos para la calibración de los métodos nuevos comparados con los previos.

- Cuando se midan los perfiles de luz, una lectura adicional inmediatamente debajo de la superficie debe ser tomada para determinar la reflexión supreficial.
- Las muestras de agua para analizar la turbidez deben ser también analizados para la concentración de sólidos suspendidos y el porcentaje del peso seco libre de cenizas del material particulado.
- Una nueva sonda de oxígeno y temperatura (con un cable más extenso) podría ser requerido para el instrumento.
- Los análisis de clorofila deben ser llevados a cabo regularmente.
- El establecimiento o mantenimiento de una estación metereológica con un piroheliógrafo cerca del sitio de la presa.

3.2.4 Mediciones de la productividad primaria.

Mediciones de la productividad primaria deben continuarse para formar parte integral del programa monitor y el método del carbono 14 debe ser utilizado. Facilidades para el conteo de centelleo son potencialmente disponibles en Tegucigalpa. En el caso de un cambio del método o del instrumento para medir la incorporación del carbono 14, cuidado debe tenerse para asegurar una intercalibración con las facilidades en Davis usados en los estudios pasados del L. Yure y L. de Yojoa.

Si no es posible continuar con el uso del método del carbono 14, entonces el método del oxígeno para medir la producción primaria debe ser empleado. Este es mucho menos sensitivo que el método del carbono 14, pero debe proveer información útil. Series paralelas con métodos del carbono 14 y del oxígeno deben ser intentados. Detalles completos del método del O_2 aparece en Wetzel y Likens (1979). Un período de incubación aproximadamente de 8 horas probablemente será requerido en el L. El Cajón aunque un período de 24 horas entre puestas de sol podría ser también considerado.

3.2.5 Bioensayos de nutrientes.

Una serie de bioensayos de nutrientes regular debe ser llevado a cabo usando la asamblea de fitoplancton de El Cajón cerca de la presa. Es recomendado que estos bioensayos se realizen mensualmente (de 4 a 6 meses) durante el primer año de la vida del embalse, para así estimar cualquier patrón de cambio en la limitación de nutrientes atraves del tiempo. La metodología de los bioensayos es descrita en la sección 5 del reporte y siempre debe incluir adiciones de nitrógeno y fósforo separados y en combinación. Concentraciones de las adiciones iniciales deben ser calculados de tal manera que la concentración ambiental se incremente aproximadamente cuatro veces más. Si una inhibición de la fotosíntesis ocurre, los niveles pueden ser reducidos.

3.2.6 Descarga de la turbina.

La descarga de la turbina debe ser muestreada a intervalos semanales. Todas las mediciones rutinarias de calidad de agua deben ser realizados en estas muestras. Además, las muestras deben ser analizadas para el suifuro de hidrógeno y la demanda bioquímica de oxígeno.

Aproximadamente a intervalos de 3 meses (trimestral), una serie de muestras longitudinales río abajo deben ser colectados, extendiéndose desde la presa hasta Santa Rita, para determinar el cambio en el río de la calidad del agua descargada desde El Cajón. De especial interés e importancia serán los cambios en las concentraciones de oxígeno y sulfuro de hidrógeno a varias distancias debajo de la presa.

3.2.7 Inspección del peligro en el embalse y sus tributarios.

Esfuerzos deben de hacerse para muestrear regularmente al menos uno de los ríos mayores que entran al embalse de El Cajón e inspeccionar todas las areas del lago por severa erosion del nivel de las playas, peligro de desgaste masivo (derrumbes) y plantas acuaticas superiores (ej. Eichhornia) e invasiones de vectores de enfermedades (caracoles).

Un reconocimiento regular del embalse debe ser realizado para identificar pendientes inestables capaces de derrumbes de desgaste masivo durante el evento de una tormenta. Estos deben ser cuidadosamente inspeccionados por los geólogos de la ENEE pues ellos representan un riesgo potencial inmutable.

Puesto que algunos caracoles presentes pueden ser vectores de schistosomiasis, las inspecciones deben controlar las poblaciones de caracoles.

Inspecciones del muestreo de los ríos facilitará la investigación de la influencia de la calidad y cantidad del agua que desemboca en el régimen de mezclado del embalse y niveles de nutrientes. El muestreo fluvial puede ser auxiliado por alguien por ejemplo que viva en Guacamaya y las muestras pueden ser recogidas mensualmente. Cuidado debe ser tomado al entrenar al individuol minuciosamente. La provisión de un congelador electrico o de kerosene podría ser una buena forma de preservar las muestras. Si esto no es posible, entonces la preservación química (con H_2SO_4, $HgCl_2$ o cloroformo) podría ser considerado. Series de pruebas deben ser practicados para determinar el efecto del método de preservación y almacenamiento en los resultados analíticos.

3.2.8 Informacion Metereológica

A fin de proveer la información necesaria de referencia metereológica para los estudios limnológicos y una comprensión micrometereológica del ambiente en el embalse, la radiación solar, temperatura ambiental, humedad relativa y precipitación deben ser medidos continuamente en una localidad cerca de la estación índice. La estación metereológica existente cerca del lugar de la presa podría ser la base más conveniente para la colección de esta información. Un medidor de viento o anemómetro podría ser una adición valiosa al sistema para anticipar eventos de mezclado.

3.2.9 Quimica de la precipitacion bruta.

La química de la precipitación bruta (ej. descenso húmedo y seco) debe ser analizado regularmente. Series de baldes plásticos, económicos y secos pueden ser colocados alrededor del área y cambiados regularmente. Tormentas individuales al principio de la estación lluviosa deben ser muestreados debido a la carga elevada de nutrientes através de la precipitación en aquel tiempo. El efecto del corte y quema en Honduras como su influencia en la fertilidad del embalse podría ser evaluado por esta colección bruta. El ph de la precipitación debe ser también regularmente medido y cuidado especial debe ser tomado para estandarizar estas medidas por calibración cruzada con otros instrumentos y la calibración con soluciones amortiguadoras (buffer) frescas cuidadosamente preparados. Un electrodo de ph adicional (repuesto) debe estar siempre al alcance.

3.2.10 El horario de muestreo.

Tomando en cuenta el actual número del personal del laboratorio, un horario prioritario y realístico de muestreo debe ser desarrollado inmediatamente. Cuidado debe ser tomado en este programa desarrollado para proveer tiempo adecuado para el análisis de las muestras y manejo de los datos. No obstante de la considerable experiencia que ha sido ganado por el personal del laboratorio, ellos pueden necesitar alguna asistencia en la implementación del programa monitor descrito en estas recomendaciones. Más adelante, probablemente podría ser deseable si la ENEE contratara personal adicional (uno o dos personas) para poner el programa posterior al embalsamiento (PIP) en marcha. Podría ser posible atraer fondos de los bancos para ayudar a implementar el PIP.

3.2.11 Deposito, recuperacion, analisis de datos y equipo.

La importancia de este aspecto del PIP no podría ser sobreestimado:

a) Las hojas de datos necesitarán ser adaptados o revisados para tomar encuenta las gran profundidad del embalse y las nuevas medidas que serán realizadas.

b) Nuevos programas necesitaŕan ser desarrollados para la computadora-maquina graficadora HP, o modificar los programas existentes del ERA para manejar los nuevos datos que serán colectados.

c) Sería deseable si la ENEE equipara al laboratorio de limnología con un pequeño y nuevo computador con pantalla de video, depósito por disco y una persona entrenada para entrar y recuperar los datos del sistema. El uso de las facilidades de una computadora existente de la ENEE podría ser arreglado con una conección através del teléfono para transferir datos, pero una computadora pequeña de tipo personal con adecuado almacenaje e impresor está llegando a ser ahora una parte esencial del laboratorio moderno. Esta unidad podría suplementar pero no inmediatamente reemplazar a la unidad HP si gráficos fuesen incluídos.

d) A pesar de las disponibilidad en el laboratorio de limnología de facilidades en computadora, la ENEE es alentado a seguir obteniendo datos y personal necesario para recombinar el modelaje hidroeléctrico con las condiciones físicas, químicas y biológicas del embalse. Este puede ser grandemente facilitado si recuerda la sección 2.2.11 del a) hasta d).

e) Un bote moderadamente rápido con motor fuera de borda equipado como si fuese un pequeño laboratorio flotante podría mostrar un valor enorme para el proyecto. Un torno de poder, almacenamiento frio y equipo de filtración podrían hacer el trabajo sinóptico mucho mas fácil y confiable.

3.2.12 Reporte anual.

El desarrollo de un reporte anual del PIP es un producto esencial de las recomendaciones del programa monitor descrito anteriormente. Sin la disciplina de acoplar los datos cada año, mucho del valor de este trabajo se perdería en su uso en las decisines importantes para el manejo del embalse. Por supuesto, algunos reportes deben ser inmediatos. Si por ejemplo Eichhornia aparece en cualquier parte del embalse un bote debe inmediatamente ser despachado con herbicidas para preveer una invasión general. Si algunos meses pasan y ninguna acción es tomada, la invasión podría esparcirse y el control sería demasiado costoso.

3.3 ESTUDIOS ADICIONALES DEL PROGRAMA LIMNOLOGICO POSTERIOR AL EMBALSAMIENTO DEL EMBALSE DE EL CAJON

3.3.1 Muestreo sinoptico.

Un muestreo sinópitco es recomendado para determinar las diferencias en fertilidad entre los diferentes brazos del embalse. Este envuelve muestreos en muchas estaciones en un período de tiempo relativamente corto para determinar la productividad, calidad de agua y estratificación del embalse. Este enfoque es particularmente valioso para la detección de control y polución. Una serie de estaciones que pueden ser recorridos durante una sola noche debe ser seleccionado o un sinóptico de tres días organizado.

a) Productividad Primaria:

Si un bote veloz es disponible, las muestras deben ser colectadas en la noche, traídas de regreso e incubarlos todos juntos en la estación índice. La selección de una noche clara haría la navegación más simple y las muestras deben ser incubadas desde el amanecer por 4 a 6 horas. Si un bote veloz no es disponible, el personal puede ser dividido en dos grupos y el muestreo sinóptico realizarse por un período de tres días.

Día 1: Estación Indice + Humuya (ej. el uso de la estación índice como un control para los diferentes niveles de luz y seleccionar tres profundidades para muestrear en cada estación).

Día 2: Estación Indice + Yure.

Día 3: Estación Indice + Sulaco.

Las Muestras de productividad pueden ser filtradas en el campo y el personal puede acampar fuera para realizar el sinóptico.

(Nota: el carbono 14 es injectado en todas las muestras justamente antes de su incubación simultánea).

b) Química de agua:

La química estándar de agua debe ser hecho en cada estación junto con el zooplancton tomado por dos tiros verticales de la red. Las muestras sinópticas a diferentes profundidades en la zona eufótica pueden ser combinados para reducir el tiempo de análisis.

3.3.2 Perfiles de estratificacion.

Perfiles longitudinales de temperatura, oxígeno, conductividad y sedimentos suspendidos (perfiles verticales de suspensoides) através por ejemplo de la rama del Humuya al inicio y termino de la estación lluviosa podría ser valioso (ver también 3.2.6 abajo).

3.3.3 Bioensayos con agua fluvial y efluente de la presa.

Agua fluvial y la descarga de la presa pueden ser ensayados en cultivos por adición de carbono 14, tomando el agua de la superficie y parte media del embalse, cerca de la presa. Esto determinará la fertilidad efectiva de los tributarios e indicará la descarga de nutrientes del sistema. Ensayos actuales pueden ser hechos con la incorporación de carbono 14, medidas de clorofila o conteos de fitoplancton. El ensayo con ^{14}C es más rápido y sensible.

3.3.4 Presupuesto de nutrientes.

El futuro modelaje del nuevo embalse requerirá del tipo de datos y esfuerzo de muestreo indicado en el apéndice 7.

3.3.5 Transectos por sonar.

Un delta empezará a in vadir desde los tributarios mayores hacia el embalse tan pronto la primera inundación llegue. Un transecto regular, anual por sonar a lo largo de los brazos principales mantendría en guardia de su progreso hacia la presa y la pérdida de almacenamiento activo. Cuidado debe ser tomado para conocer la elevación precisa de la superficie del embalse durante estos transectos anuales. Los transectos deben ser realizados al mismo tiempo cada año y quizás ser seleccionados de acuerdo a la elevación del agua del embalse durante el inicio de la estación seca. Sería ideal escoger una fecha donde la entrada y descarga sean casi iguales.

3.3.6 Investigacion de la limitacion de luz en la productividad primaria del fitoplancton.

La zona eufótica posiblemente sea menos de 3 veces la profundidad del disco de Secchi. Transectos de transparencia a lo largo del embalse pueden comprobar su valor en la determinación del volumen productivo del embalse y pueden identificar la extensión de la limitación de luz en las porciones más turbias del embalse. Debido a que este fenómeno es correlacionado grandemente con la conducta de los aflujos turbios, los perfiles verticales de las vertientes acarreando sedimentos pueden probar ser importantes. La profundidad de estos vertientes pueden ser aparente através de los perfiles de conductividad y temperatura.

3.3.7 Analisis de bacterias coliformes.

Una programa para el transecto de muestreo longitudinal en el Humuya para los análisis de bacterias coliformes deben ser conducidos durante períodos de flujo bajo. El compromiso de la agencia de Salud Pública en este trabajo es fuertemente recomendado. El suplemento de agua potable podría también ser revisado para los habitantes locales.

3.3.8 Estratificación y química de agua.

La limnología de las áreas claras y turbias del embalse se compararán para la estratificación y química de agua. Una atención particular debe ser dirijido hacia los perfiles de oxígeno y sulfuro de hidrógeno através de la columna de agua.

3.4 PESCA

3.4.1 Muestreo del embalse.

Al inicio del año 1985, series de redes de longitud estándar y tamaños de mallas deben ser usados regularmente en las diferentes partes del lago. Debido a que el área del lago es grande en relación al del L. Yure y debido a que la captura por unidad de esfuerzo fue baja en este último lago, un número adicional de series de tamaños de redes multifilamentados deben ser fabricados. El muestreo debe ser concentrado inicialmente en aquellas áreas de la línea de playa donde la pendiente es más llana y aquellas áreas cerca del aflujo de los tributarios. A medida que la pesca del lago llegue a ser más productiva, el muestreo debe incluir un mayor número representivo de habitat entrelazados. El brazo del Yure y al menos uno de los brazos del Humuya y Sulaco deben ser seleccionados. Desde el inicio de este programa, un mayor esfuerzo debe de hacerse para estándarizar el equipo y horario de pesca asi como del análisis y reporte.

La serie de redes deben ser colocados inicialmente en una variedad de profundidades dentro de la zona sugerida. Después de estas pruebas, la zona con mayor captura por unidad de esfuerzo puede ser seleccionado. Ya selectos estas localizaciones pueden ser marcados y pescados al mismo tiempo cada año con el mismo equipo de ese modo estimar un índice de abundancia. Algunas series de redes deben colocarse en ángulo perpendicular a la costa y pescados tan profundo como el oxígeno este presente. Experimentos deben ser conducidos con varias trampas de peces para determinar su útilidad.

Transectos rutinarios por sondeo de eco del lago deben ser realizados para determinar el desarrollo de cualquier población de peces pelágicos y la localización de las áreas menos problematicas para las series de redes. La localización nocturna por eco podría ser requerido para localizar cardumenes de peces migrando del litoral en la noche.

Si poblaciones pelaguicas se desarrollan, se debe de dar consideración a la obtención de una pequeña red; a nivel medio y de pesca de arrastre para realizar el muestreo en aguas abiertas (en la superficie o a profundidad media) podrían ser efectuados en un esfuerzo para muestrear estos peces.

3.4.2 Especies de importancia economica.

La condición reproductiva y dietas deben ser análizadas para todos los peces (o una submuestra) tomados durante la pesca experimental. Una atención debe ser dada a los siguientes especies en vista de su potencial importancia, sea como alimento para los humanos o como un componente de la red trófica de la comunidad de peces del embalse: *Cichasoma motaguense*, *C. managuense*, *C. maculicauda*, *C. spilurum*, *Rhamdia* spp., *Astyanax fasciatus*, *Brycon guatemalensis*, *Melaniris guatemalensis* y las especies introducidas de *Ictalurus*, *Sarotherodon* y *Micropterus* (bass negro). Estas tres especies introducidas están ahora presentes en los ríos Humuya y Yure. Su desarrollo en el nuevo embalse debe ser monitorizado estrechamente. Las poblaciones de *Melaniris* deben ser muestreados intensamente, en vista de su potencial importancia como pez que se alimenta en aguas abiertas. Alguna forma de censo por pesca de arrastre o sonda de eco probablemente será necesario para muestrear estos peces adecuadamente.

3.4.3 Razon de crecimiento de los peces.

Las razones del crecimiento de las especies de cíclidos y de las especies de Rhamdia deben ser investigados utilizando los métodos descritos en las secciones 5 y 11. Esfuerzos iniciales debe concentrarse en determinar cuando las marcas de los anillos de crecimiento son colocados en las escamas, otolitos y vertebras. Comparaciones de las razones de crecimiento deben ser hechos con aquellas especies estudiados en el L. Yure y el río Yure. La factibilidad de continuar con el uso del método de cohorte para la estimación de la razón de crecimiento debe ser investigado y tomar una decisión con relación a su continuidad (vease sección 11.5).

3.4.4 Dietas y estudios de cadenas alimenticias.

Una comparación de las dietas, distribución y el suceso reproductivo de las dos especies de cíclidos C. motaguense y C. managuese debe ser realizado. Estos peces ecológicamente semejantes podrían ser importantes como alimento.

El suplemento de alimentos para peces debe ser investigado a través de series de colecciones de zooplancton y bentos. Redes de emergencia pueden ser útiles para insectos acúaticos. La composición de las especies de zooplancton y su relación con la comunidad desarrollada de peces debe ser examinada. La atención debe enfocarse en cualquier cambio marcado en tamaño, especies dominantes y contenido estomacal de peces. Comparaciones de las dietas de los peces deben ser realizados entre áreas claras y turbias del embalse.

Para examinar más adelante las interaciones entre pez y zooplancton, series de experimentos de alimentación en el laboratorio deben ser empezados, concentrándose inicialmente en Astyanax y Melaniris.

3.4.5 Muestreo de peces rio abajo.

El área inmediatamente río abajo de la represa debe ser muestrado regularmente, especialmente para especies como *Pomadasys* y *Centropomus*. Podría ser valioso comparar la fecundidad de los peces capturados en el embalse y en los ríos (comparando los estudios ya realizados en el sistema de Yure). Podría también probar ser útil comparar los pesos secos de los huevos en estasdos poblaciones y variaciones de este parámetro.

La estacionalidad de reproducción de los especies mayores ya citados (3.4.2) debe ser comparado con los datos básicos fluviales especialmente para ver si la reprodución en el lago es más continuo através del año.

3.4.6 Muestreo y manejo de la pesca en el embalse.

En base a las investigaciones iniciales de la pesca en el embalse y datos existentes de los estudios fluviales y del L. Yure, se determinará las estaciones de reproducción y las áreas principales de desove en el embalse.

Los estudios deben ser continuados (muestreo de > 2 años) en el L. Yure para documentar futuros cambios en especies y el desarrollo de las población de peces.

Ninguna introducción de peces o zooplancton debe ser esperado al menos en 5 o 6 años. El embalse será casi ciertamente colonizado por las tres especies exóticas presentes, *Micropterus*, *Ictalurus* y *Sarotherodon*. Más tarde, la introducción del cíclido *C. urophthalmus* debe ser considerado si es que no está presente ahora en el lago, puesto que su alimento principal (en el lago de Yojoa) son los caracoles uno de los cuales incluye al género *Biomphalaria* que podría ser un vector potencial de schistosomiasis.

El 'nicho' pelágico será especialmente importante en el L. El Cajón pues el lago tendrá una zona litoral muy limitada. Esfuerzos deben ser puestos en determinar si cualquiera de las especies nativas están ocupando este nicho. Si no es así, otras especies centroamericanas podrían ser consideradas para su introdución.

Intentos para determinar la cantidad de tiempo que pasan pescando las personas que viven cerca del embalse y sus éxitos por unidad de esfuerzo. Este censo de canastos puede ser realizado enviando grupos al campo para entrevistar a las personas y acompañarlos a pesar. Cuando los pescadores son encontrados en el lago, ellos pueden ser interrogados con una hoja de entrevista estándar por los biólogos. Posteriormente, el marcado de peces podría mejorar la estimación de las poblaciones de peces.

La pesca de anzuelo, trampa y redes en el embalse debe ser permitida pero las tallas de las mallas deben ser controladas para a sí proteger a los peces juveniles. Cuando las áreas de desove son localizados, puede que sea necesario prohibir la pesca en algunos de estas áreas durante ciertos períodos.

3.4.7 El Desarrollo de pesca comercial y deportiva.

Si una pesca comercial o deportiva se desarrolla en el L. El Cajón, el conjunto de datos desarrollados de estos estudios indicados (3.4.1 hasta 3.4.6) es esencial. La existencia de la electricidad bárata de la presa podría hacer posible una planta de hielo o un pequeño congelador si la población de peces alcanza niveles adecuados para sustentar una cosecha estable de peso y valor comercial significativo. Un programa de relaciones públicas con anuncios informativos para los pescadores de la recompensa al regresar marcas, etc. puede ser desarrollado para educar los pescadores locales acerca de los enfoques de la regulación y manejo como parte del programa en desarrollo por el laboratorio.

Después que suficiente información es obtenida en las estaciones y localizaciones de desove, se desarrollarán regulaciones simples de pesca en el embalse para proteger los peces en épocas importantes de desove y acelerarar una pesca viable. Un programa educacional podría ser útil y un guardia de pesca será requerido para hacer cumplir estas regulaciones.

Debería ser posible y deseable el desarrollo de un criadero experimental de cocodrilos o caimanes adyacente al embalse. Estos reptiles son ahora una especie en peligro de extinción y probablemente solo sobrevivirían si son protegidos en santuarios o son criados comercialmente. En Africa y Nueva Guínea, el criado de cocodrilos por sus cueros tan extremadamente valiosas han llegado a ser una industria importante. La cría del caimán ha sido por mucho tiempo provechosa en los EEUU. Los criaderos tienen también un beneficio económico adicional, la atracción de turistas. Las cabezas y vísceras de peces pescados en el embalse y especies indeseables podrían ser usados para reducir los costos de alimentación. Un proyecto piloto muy pequeño podría ser iniciado con uno o dos pares de animales capturados en el embalse. La estancia podría establecerse cerca de la presa o del laboratorio y podría ser manejado por un zoólogo o herpetólogo interesado del personal existente del laboratorio o de la universidad. Sin tal esfuerzo, los animales atrapados detrás de la presa serán probablemente exterminados por cazadores furtivos en corto tiempo. El Fondo Mundial de Vida Silvestre podría estar interesado en financiar este proyecto. Un consultor experimentado en la cría de cocodrilos o caimanes podría ser obviamente muy útil en el inicio de este proyecto.

3.5 COOPERACION INTER INSTITUCIONAL EN EL PROGRAMA POSTERIOR AL EMBALSAMIENTO

1) Cada intento debe ser realizado para el desarrollo de estudios en cooperación con COHDEFOR. Por ejemplo, series de estudios en la química del desagüe y carga de sedimentos que se efectua actualmente en la cuenca del L. Yure podría ser extendido a la cuenca del L. El Cajón. Experimentos de bioensayos con el desagüe de lluvias y sedimentos podría ser incluidos con aquellos descritos en 3.1.

2) Escoger y estudiar intensamente dos cuencas fluviales, uno forestado y el otro no, para examinar y comparar las fluctuaciones en sedimentos y la producción de nutrientes. Este proyecto podría beneficiarse grandemente con la participación activa de COHDEFOR.

3) La colaboración con DIGENENARE (Dirección General de Recursos Naturales Renovables) en el desarrollo de los programas de manejo del embalse, especialmente los aspectos de la pesca, permanece una meta anhelada. Lo mismo aplica a Salud Públia y el control de vectores.

4) Programas en progreso con la Universidad Autónoma de Honduras donde los estudiantes realizarían prácticas en el laboratorio llevando a cabo pequeños proyectos de investigación. Este podría ser muy beneficioso y proveerá experiencias que transmitirán a la próxima generación de biólogos.

5) El inicio de un curso práctico regular de limnología en el laboratorio para estudiantes. Este curso no necesitaría ser enseñado precisamente por el personal del laboratorio (ej. personas de la universidad podrían tomar cargo), pero tenderá a fomentar una mejor cooperación con la institución académica. La Organización de Estudios Tropicales podrían casi por cierto participar en un curso de limnología tropical.

6) Continuar con el compromiso del laboratorio de limnología en otros proyectos relacionados con recursos acuáticos de la ENEE. Este proveería una importante retribución por su inversión en el PIP.

7) Considerar la compra de un analizador de absorción atómica para el análisis de metales. Este podría ser muy útil para el proyecto y podría recibir muestras a condición comercial para ayudar a financiar su costo.

8) Acoplar una presentación escrita del PIP de El Cajón para la publicidad del trabajo de la ENEE y otras agencias. Un pamfleto ilustrado de aproximadamente 20 páginas dando un resumen de los proyectos realizados y tipo de trabajo por hacer en el futuro podría ser una contribución valiosa para hacer

conciencia pública de la naturaleza multidisciplinaria de los programas de el Cajón y las facilidades disponibles para trabajos relativos con recursos acuáticos en Honduras.

4. SAMPLING STATIONS AND SCHEDULES

4.1 INTRODUCTION

This section describes the overall framework of the Limnology and Fisheries Program. Methodology employed during the study will be discussed in detail in section 5. The program was designed to enable sample collection over a wide area, both within the El Cajón watershed and downstream from the dam site. As the program progressed, effort centered on more restricted areas, so that broad, reconnaissance-type surveys were complemented by more site-intensive studies of certain aspects of the ecology of the El Cajón area. The overall nature of the program and the number and experience of personnel involved, meant that it was generally not possible to extend the work to extremely detailed, specific limnological or ecological investigations. Future work at the Limnology Laboratory will be able to capitalize on the base of information and experience built up since 1979 to further develop studies in those areas which are of special importance to the El Cajón hydroelectric project and to the region as a whole.

4.2 WATER QUALITY MONITORING PROGRAM

4.2.1. River studies

In 1979 a network of fifteen stations was established in order to monitor river water quality in the El Cajón watershed and area downstream from the dam site. These stations are shown in Fig. 4.1 the exact locations are described in Appendix 1. Table 4.1 summarizes the sampling schedule of the water quality monitoring program.

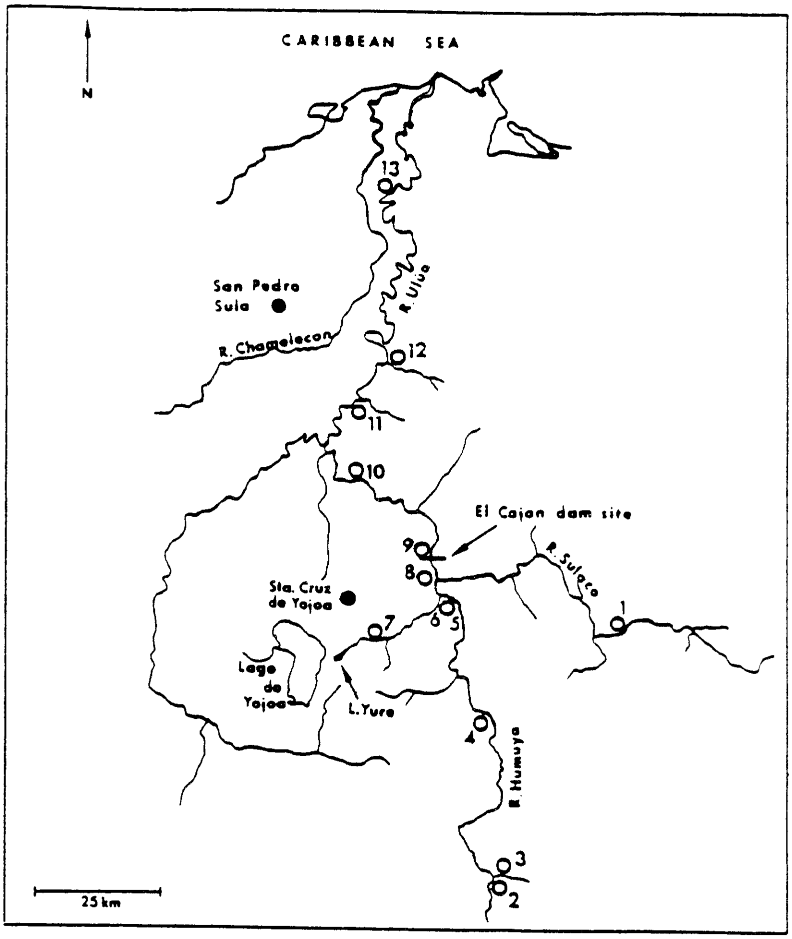

Figure 4.1: Map of the El Cajón area showing sampling stations for the river quality monitering program.

Figura 4.1: Mapa del área de El Cajón señalando las estaciones de muestreo para el programa de calidad agua fluvial.

Station key:

1. R. Sulaco at Victoria
2. R. Humuya at Comayagua
3. R. Chiquito at Comayagua
4. R. Humuya at Ojos de Agua
5. R. Humuya at Yure confl.
6. R. Yure at Humuya confl.
7. R. Yure at Yure
8. R. Humuya at Sulaco confl., R. Sulaco at Humuya confl.
9. R. Humuya at El Cajón
10. R. Humuya at Santa Rita
11. R. Ulúa at San Manuel
12. R. Ulúa at El Progreso
13. R. Ulúa at Guanacastales

Table 4.1: Sampling schedule employed in the limnology program.

Tabla 4.1: Horario de muestreo utilizado en el programa limnológico.

River/Lake	Station	Period Sampled	Sampling Frequency	Station # (Fig. 4.1)
Sulaco	Victoria	XI/79 - VII/81	4 wk	1
Chiquito	Comayagua	X/79 - I/81	4 wk	3
Humuya	Comayagua	X/79 - I/81	4 wk	2
Humuya	Ojos de Agua	X/79 - I/81	4 wk	4
Humuya	conf. R. Yure	XI/79 - I/81	4 wk	5
Yure	conf. R. Humuya	XI/79 - I/81	4 wk	6
Yure	Yure	X/79 - XII/81	2-4 wk	7
Humuya	conf. R. Sulaco	IX/79 - IV/82	1-4 wk	8
Sulaco	conf. R. Humuya	XII/79 - XII/8	2-4 wk (dry seasons only)	8
Humuya	El Cajón Dam Site	IX/79 - X/82	1 wk	9
Q. El Cajón	nr. dam site	X/79 - X/80	2 wk	—
Humuya	Santa Rita	X/79 - IX/80	4 wk	10
Ulúa	San Manuel	X/79 - IX/80	4 wk	12
Ulúa	El Progreso	X/79 - IX/80	4 wk	11
Ulúa	Guanacastales	X/79 - IX/80	4 wk	13
Lago de Yojoa	Index	XI/79 - XI/82	3-4 wk	--
Lago Yure	Index	XI/79 - XI/82	1-3 wk	—
Lago Yure	QSN	I/80 - II/82	various	--
Lago Yure	QdC	I/80 - II/82	various	—
Lago Yure	QT	I/80 - XI/82	various	--
Q. Sin Nombre	--	I/80 - IX/82	2-3 wk	—
Q. del Cerro	--	I/80 - IX/82	2-3 wk	--
Q. Tepemechín	—	I/80 - VI/82	2-3 wk	—
Yure-Yojoa Canal	--	I/80 - IX/82	2-3 wk	--

4.2.1.1 Downstream stations: Of the four stations located below the dam site, two were chosen in order to evaluate the relative contributions of the Humuya and Ulúa rivers to the water quality of the lower section of the Ulúa. At Santa Rita the Humuya was sampled a short distance above its confluence with the Ulúa. Water quality at this station could then be compared to that at San Manuel, just below the Ulúa confluence. The lower Ulúa was monitored at El Progreso and Guanacastales. Water quality at the latter station probably closely represents that of the Ulúa as it flows into the Caribbean.

It was not possible to calculate loading rates from the information on nutrient and sediment concentrations as adequate flow data were not available for the three lower stations and the program was not equipped to measure flows of larger rivers. A comparative analysis of river quality at various points below the El Cajón dam site was possible, however, since all four downstream stations were always sampled on the same day.

4.2.1.2 Watershed Stations: Sampling was routinely carried out at a total of ten stations within the El Cajón watershed (defined for present purposes as the region upstream of the dam site, i.e., including areas to be inundated by the dam). Each of the three major rivers (Humuya, Sulaco and Yure) was sampled from at least two stations, one upstream and a second just above its confluence with the other major river (Fig. 4.1, Table 4.1). The station at Ojos de Agua represents the approximate location of the upper extension of the Humuya branch of the future reservoir. It formed part of a three-station set which was monitored in order to evaluate the potential significance to the future reservoir of the discharge of waste-water from the city of Comayagua. Waste-water is discharged into the Río Chiquito, a small river just to the north of Comayagua, which joins the Humuya a few kilometers downstream from the point of sewage input. By sampling the R. Chiquito and the R. Humuya both above and below its confluence with the Chiquito (at Comayagua and Ojos de Agua, respectively), it was possible to estimate the relative contribution of the latter river to the overall nutrient loading from the Humuya.

Because of problems of access, it was not possible to sample a station equivalent to Ojos de Agua on the R. Sulaco, i.e. at Las Lomas de El Jícaro, located at the upper extension of the Sulaco branch of the future reservoir. However, Victoria is about 10 km above this point and was thus used as the upstream station for the Sulaco. Most of the upstream stations in the El Cajón watershed were sampled at monthly intervals. The most important sampling sites in the water quality monitoring program were the two stations at the Humuya/Sulaco confluence (#8, Fig. 4.1) and, especially, the station at the dam site itself (#9, Fig. 4.1). Water quality as monitored at the latter station effectively represents an integration of all the various inputs from the El Cajón watershed. Because of this, sampling frequency was highest at the dam site station, and monitoring was continued for almost the entire duration of the program. The exact point of sample collection was changed, in January 1981, from immediately below to just above the dam site, in response to the discharge of material from tunnel excavations (See Appendix 1). Analysis of dam site samples attained additional significance later on in the program, with the development by the Limnology Laboratory of a separate program for ENEE/Motor Columbus to investigate the nature of several of the water sources encountered in the site tunnels. A small stream entering the Humuya river just below the dam site, Quebrada El Cajón, was sampled biweekly during the first year of the program. This stream was chosen to provide a comparison with the seasonal fluctuations in nutrient levels of the larger rivers within the El Cajón watershed. The baseline limnological information obtained from Q. El Cajón was also useful in relation to the series of invertebrate samples taken from this stream (see section 4.2.2).

In addition to the routine monitoring program, two other, smaller, studies of river water quality were undertaken. The first of these, carried out between November 1981 and July 1982, was an environmental impact study for a proposed river diversion/dam project on the Tamalito river. This study was under the direction of the resident limnologist, but much of the field sampling was done by persons employed specifically for the project, in order that there would be no conflict with the demands of the El Cajón limnology program. This study is discussed in more detail in Appendix 6.

The second additional study involving water quality was an intensive monitoring of suspended sediment loading at two stations on the Humuya river (Ojos de Agua and Piedra Parada, near the Sulaco confluence {Stations 4 and 8, Fig. 4.1). This study was designed to estimate the change in suspended solids loading over that stretch of the river which will form the Humuya branch of the reservoir. The first phase of the study was carried out in November 1981, and the second phase in September 1982. Water samples were collected three times per day at both stations, over periods of approximately two weeks. Results of this study will be integrated into the general discussion of river water quality (section 6.2.6).

4.2.2 Lake studies

Considerable emphasis was placed on limnological investigations of Lago de Yojoa and Lago Yure. The relevance of these lake studies has already been discussed in the introduction to the report, and later sections will present a more detailed integration of this work with data from the river water quality monitoring program.

During the first year of the program, both lakes were sampled every three weeks. It soon became clear, however, that not only were the L. Yure studies going to be of more relevance to the overall El Cajón program, but also that, in contrast to L. de Yojoa, L. Yure presented much more variability (both spatially and temporally) in many aspects of its limnology. It was thus decided to modify routine sampling frequencies to once every two weeks and three weeks for L. Yure and L. de Yojoa, respectively.

Sampling in both lakes was concentrated at an index station. In L. de Yojoa, this was located in mid-lake, off the Agua Azul Hotel (Fig. 8.1). Two other stations in L. de Yojoa (1 and 2 in Fig. 8.1) were abandoned after a few months when it became clear that inter-station variability was minimal in this lake.

The index station of Lago Yure was located near the dam spillway, one of the deepest areas of the lake (Fig. 7.1). In addition to the index, stations were also established in each of the three main branches of the reservoir. These were sampled every 3 weeks during the first year of the program and more infrequently thereafter. The three principal tributaries to L. Yure, Q. Tepemechín, Q. del Cerro and Q. Sin Nombre*, were sampled on the same days as the lake index station. Thus, a routine sampling day at L. Yure covered the index station, 3 streams and, at times, the 3 stations of the principal reservoir branches. In this report, the branches of the reservoir are identified by the following abbreviations (in order to distinguish them from the streams themselves): QT, QdC, QSN.

A series of bioassays was carried out to investigate which nutrients were limiting to algal primary production in L. Yure. Most of these bioassays were

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*(Note that the 3 tributaries have been assigned names in accordance with the topographical maps of the area. The maps appear to be in error, however, since people living around L. Yure use R. Yure for Q. Tepemechín which is logically correct , Q. Tepemechín for Q. del Cerro, and Q. del Cerro for Q. Sin Nombre.).

carried out between June and September 1981. Full details are included in sections 5.1.5 and 7.6.

4.3 BIOLOGICAL PROGRAM

4.3.1 Plankton

Primary productivity (the growth rate of planktonic algae) was increased regularily at the two lakes. Samples of phytoplankton and zooplankton were routinely collected from both lakes as part of the limnological monitoring program. They were generally taken at the index stations, but occasionally from other areas of the lakes as part of synoptic surveys. During the second year of the program, zooplankton sampling frequency was increased to once every two weeks in L. de Yojoa in order to better document population dynamics in that lake. Biweekly zooplankton samples were also taken from L. Yure, until July 1982, when sampling frequency was greatly increased following dramatic changes in the composition of the zooplankton assemblage.

4.3.2 Invertebrates

The invertebrates of Q. El Cajón, a small stream which flows into the R. Humuya just below the dam site, were sampled every two weeks during the first year of the program. This sampling documented the population dynamics of invertebrate groups which are often of trophic (for fish) or of medical importance.

Invertebrate samples were also collected from time to time in other rivers, especially the Río Yure. This material was used principally as a reference collection for studies on fish diets.

On a number of occasions throughout the program, samples were collected of the developing benthic invertebrate fauna of L. Yure. This fauna represents a component of the system which is of particular importance to the lake fishery.

The other demands of the program meant that an in-depth, quantitative study of benthic invertebrates could not be undertaken. A qualitative documentation was, however, adequate for the studies on fish ecology.

4.3.3 Fish

Fish sampling was started in September 1980 and included a wide variety of habitats throughout the El Cajón watershed (section 11). A few of the stream sites were sampled repeatedly throughout the program, (e.g. R. Yure at Yure), in order to fully document seasonal changes in reproductive and feeding ecology. Other sites were sampled only once or twice, the principal objective here being a distributional analysis of the important species present in the watershed.

Considerable effort was invested in studying the developing fishery of L. Yure, because of its obvious relevance to the future El Cajón fishery. Fish sampling began in September 1980 and continued until the end of the program. The frequency of fish sampling changed somewhat as the program progressed and is described in Volume II, section 11 of this report. Additional description of the sampling sites is included with the discussion of the results of the fisheries studies. Recommendations for the Post Impoundment Program in Fisheries are included in section 11.

5. METHODS

5.1 PHYSICAL AND CHEMICAL LIMNOLOGY (RIVER AND LAKE STUDIES)

5.1.1 Field Sampling

River water samples were collected in duplicate by immersing plastic containers to mid-depth. Wherever possible, samples were taken from mid-river. However, in the larger rivers, high wet season discharge rates at times prevented this. Sampling was then done a few meters from the bank. On two occasions (October 1981) a boat was used to obtain mid-river samples (otherwise unobtainable) from 3 stations near the dam site. At each station, bank samples were also collected for comparative purposes. Table 5.1 shows that mid-river and bank samples were generally similar in terms of nutrient and suspended solids concentrations. In the Humuya river, however, both above and below the confluence, silica concentrations were higher in samples taken from mid-river. Similarly, there was a tendency for mid-river samples to show higher suspended solids concentrations than bank samples, at least in the upper range of concentrations.

Lake water samples were collected with a 2.5 l transparent plastic Van Dorn bottle. Either discrete-depth or composite-depth samples were taken. In the latter case, discrete samples, collected at regular depth intervals through the euphotic zone, were combined to yield integrated water samples.

Two sets of (duplicate) samples were collected at each river site or lake depth. A third sample, for suspended solids analysis, was collected at the river stations. In the field, one of these sets was filtered through G F/C and 0.45 um HA Millipore filters (previously rinsed with distilled water) using a Millipore Swinnex filter holder and syringe. The other set(s) was left

Table 5.1: Influence of sampling location on water quality parameters. (Data represent means and standard deviations of duplicate samples).

Tabla 5.1: Influencia de la localización del muestreo en los parámetros de calidad de agua. (Datos representan promedios y desviaciones estandard de muestras duplicadas).

Date	Station	Site	Total-P (μg/l)	PO_4-P (μg/l)	NO_3-N (μg/l)	NH_4-N (μg/l)	SiO_2 (mg/l)	Fe (mg/l)	Susp. Solids (mg/l)
21-X-81	R. Humuya, El Cajon	Mid-river	44 (2)	20 (1)	51 (3)	14(3)	11.4(1.4)	.47(.02)	45
		Bank	49 (6)	21 (0)	51 (3)	9(1)	10.9(1.9)	.46(.02)	46
28-X-81		Mid-river	552(100)	38 (1)	46 (4)	8(1)	25.2(2.1)	2.41(.09)	3020
		Bank	321 (32)	38 (1)	48 (1)	37(4)	8.2 (.1)	1.98(.08)	2930
21-X-81	R. Humuya, Sulaco confl.	Mid-river	62 (4)	33 (1)	52 (2)	9(3)	13.6 (.4)	.58(.01)	52
		Bank	60 (2)	32 (1)	50 (0)	12(5)	4.0 (0)	.74(.04)	49
28-X-81		Mid-river	280 (4)	76(16)	88 (2)	108(6)	45.2 (.1)	2.58(.02)	5320
		Bank	288 (2)	59 (4)	90 (7)	109(0)	23.9(1.3)	2.47(.36)	4040
21-X-81	R. Sulaco, Humuya confl.	Mid-river	30 (1)	9 (0)	48 (2)	12(1)	5.7(2.8)	.27(.01)	48
		Bank	32 (1)	10 (1)	43 (1)	13(6)	8.1 (.9)	.35(.01)	50
28-X-81		Mid-river	102 (2)	28(10)	76(16)	15(1)	9.2 (.2)	.76(.01)	366
		Bank	100 (6)	21 (1)	74 (4)	14(2)	9.7 (.4)	.97(.07)	342

unfiltered. All samples were maintained cool until returned to the laboratory. Table 5.2 provides a summary of the sampling operation, listing the parameters routinely measured in the field and the laboratory analyses carried out on the samples.

Conductivity was measured _in situ_ using a Yellow Springs Instrument (YSI) Model 33-S-C-T meter. Temperature and dissolved oxygen were measured _in situ_ using a YSI model 51B oxygen meter and combination probe. All three parameters were measured at meter intervals in the lakes and at mid-depth at the river stations. pH was measured on water samples, shortly after collection, using a Markson, Model J-85, portable pH meter. During the latter half of the program, this meter became unreliable, and the laboratory meter was used for field

Table 5.2: Summary of parameters routinely measured in the limnology program.

Tabla 5.2: Resumen de los parámetros medidas rutinariamente en el programa limnólogico.

	Sample			Measure
Field	- Phytoplankton - Zooplankton - Water (3 sets of samples)			-Conductivity -Temperature -Dissolved oxygen -pH -Flow (streams) -Secchi depth (lakes) -Light (lakes) -Primary productivity (lakes)
	(1)	(2)	(3)	
	Filter (2x200ml)	Not-Filtered (2x450ml)	(1x450ml)	
Laboratory				
-immediate analysis		-Alkalinity -Turbidity -Fluorescence (lakes)	-Suspended solids (rivers)	
-subsequent analyses	PO_4-P NO_3-N $(SO_4)_*$ $(Cl)_*$	Total-P NH_4-N SiO_2 Fe $(Mg,Ca,N,K)_*$		

* non-routine analyses

measurements of pH in the lake studies. This meter was not used at the river stations, in order to reduce the possibility of instrument damage.

Stream flow was initially measured using a Pygmy Price flowmeter (Kahl Scientific) and subsequently with a Marsh-McBirney electronic portable water current meter. Stream velocities were measured at 60% of maximum depth at each of 10 to 15 points across a stream transect. Outflow from L. Yure (via the canal to L. de Yojoa) was measured whenever possible with a flow meter. Since high lake levels prevented these measurements being made during the wet season, canal discharge was estimated using daily readings from a gauge installed at the lake in January 1981. A calibration was established between lake water level and canal flow, measured either with a flowmeter (at low lake levels) or by noting the time taken by a float to travel a known distance along the canal, whose depth of water was known. The equation relating lake level to canal discharge was:

$$D = 11.098 + 5.53\,(G) \qquad (R^2 = .98)$$

where D = Canal discharge (m^3/sec.)

and G = Gauge reading (m)

(levels below spillway are negative)

Light penetration in L. Yure and L. de Yojoa was measured both by a 20 cm diameter Secchi disc suspended from a rope marked every 0.1 m, and by a submersible photometer (Kahl Scientific) equipped with a selenium photosensor and Lambert cosine corrector plates. A deck cell allowed simultaneous measurement of surface and subsurface irradiation.

Solar radiation was measured continuously with a recording Belfort pyrheliograph. During the first year of the program, the instrument was located at the laboratory in Santa Cruz de Yojoa. Subsequently it was moved to the meteorological station at Santa Elena, closer to both L. Yure and L. de Yojoa.

5.1.2 Laboratory Analyses

Alkalinity, turbidity, suspended solids and fluorescence were measured on the raw (non-filtered) samples as soon as possible upon returning to the laboratory from the field. Samples to be used for subsequent nutrient analyses were frozen.

Total alkalinity was measured by titrating 0.02 N HCl into a 100 ml sample until a pH of 5.1 was reached (APHA 1975). Dissolved inorganic carbon concentrations (needed for calculating primary productivity) were determined from total alkalinity, pH and temperature according to tabulated values in Wetzel and Likens (1979). Turbidity, measured in Nepelometric Turbidity Units, was determined using a Fisher DRT-15 portable turbidometer. Fluorescence was determined (on lake samples only) with a Turner fluorometer.

Measurements of suspended solids were made by filtering a known volume of water through pre-combusted, pre-weighed GF/C filters. Filters were dried at 103^{o}C for 1 hour, cooled in a desiccator, re-weighed, combusted for thirty minutes at 550^{o}C and again re-weighed. All weights were determined to the nearest 0.1 mg on a Mettler H31 balance. Ash free dry weight (which, when expressed as a percentage of the pre-combustion weight of suspended solids, is equivalent to "% combustible suspended solids" in Appendix 2) was calculated from the weight change following combustion of filter + sample.

At intervals of approximately one month, stored water samples were thawed and analyzed for ammonium and nitrate nitrogen, total and soluble reactive phosphorus, total silica and total iron. Ammonium-N was determined by the indophenol method (Solórzano 1969), (nitrate + nitrite)-N by the hydrazine reduction method (Kamphake *et al* 1967) and both total and soluble reactive phosphorus (PO_4-P in Appendix 2 *et seq.*) by the ascorbic acid-molybdate method (APHA 1975). Silica was analyzed by the molybdosilicate complex method (APHA 1975) and iron by the ferrozine method (after Stookey 1970). Sulfate was determined with the turbidimetric method (APHA 1975) and chloride with the argentometric method (APHA 1975). The last two analyses were not carried out routinely in either the lake or river studies, but were introduced principally on behalf of the program for monitoring dam site tunnel water quality.

All of the above eight methods are spectrophotometric analyses. A Perkin-Elmer Coleman model 55 spectrophotometer was used, with either 1, 4, or 10 cm quartz glass cuvettes. Appendix 9 provides a full description of the water chemistry methodology used at the Santa Cruz laboratory.

Cation analyses (calcium, magnesium, sodium and potassium) were performed at Davis on samples prepared in Honduras. The preparation consisted of adding 1 ml conc. HCl and 0.5 ml conc HNO_3 to 50 ml of unfiltered lake or stream water and autoclaving the samples at 15 psi and 240°C for fifteen minutes. The prepared samples were stored in 50 ml polyethylene bottles, shipped to Davis, and analyzed on a Perkin Elmer 2380 atomic adsorption spectrophotometer. Standards were made using deionized water with identical acid concentrations as the samples.

Chlorophyll _a_, corrected for degradation products (i.e. phaeophyton) was determined periodically by extraction in 90% acetone (Strickland and Parsons 1972). A known volume of lake water was filtered through a GF/C filter in the field. The filters were folded, wrapped in aluminum foil, placed in a desiccator and stored in the freezer until analyzed.

5.1.3 Primary Productivity

Phytoplankton primary productivity was measured _in situ_ in L. Yure and L. de Yojoa using the sensitive ^{14}C method (Steemann-Nielsen 1952) as modified by Goldman (1963). Two light and one dark 125 ml Pyrex bottles were filled with water collected at intervals of 1 m (L. Yure) or 3 m (L. de Yojoa) through the euphotic zone. The bottles were injected with 0.25 ml (L. Yure) or 0.5 ml

(L. de Yojoa) of ^{14}C labelled sodium bicarbonate, (with an activity of 5 µCi/ml) and suspended at the depths of collection. Bottles were incubated for approximately four hours, this period including the interval between 1100 and 1300 hours. After the incubation period the bottles were brought to the surface and immediately placed in a light-tight box. Care was always taken to shade bottles (especially those from deeper water) from direct sunlight while they were being placed into and removed from the water. This was necessary in order to prevent "light shock" in algal cells adapted to low light conditions. After the samples had been returned to the laboratory, 30 ml (L. Yure) or 50 ml (L. de Yojoa) sub-samples were vacuum filtered (at not more than 10 psi) onto 0.45 um HA Millipore® filters. These filters were then dried, packaged and sent to Davis, where the amount of photosynthetically incorporated ^{14}C trapped on the filters was measured by an ultra-thin window gas flow Geiger Müller counter (counting efficiency was about 24%). Primary productivities measured during the four hour experimental periods were extrapolated to daily rates using the pyrheliograph records of net incident solar radiation.

5.1.4 Biochemical Oxygen Demand

Five day biochemical oxygen demand (BOD) was measured periodically on both lake and river water samples. Two methods were employed. The first used a HACH manometric BOD apparatus, which continuously monitors the reduction in gaseous oxygen during the course of an incubation. The second method (APHA 1975) involves Winkler analysis of the oxygen concentration of the water sample before and after a 5-day incubation. All experiments were carried out at 20°C using an ordinary refrigerator converted to an incubator with a HACH Incutrol 12 temperature regulator.

5.1.5 Bioassays

Nutrient enrichment bioassays were performed on L. Yure water with its natural phytoplankton assemblage using the sensitive ^{14}C uptake methodology described by Goldman (1963, 1969). Twenty liters of lake water were mixed with 2 ml of ^{14}C (25 μCi/ml) and 10 ml of a supersaturated solution of $MgCO_3$ (1 g in 100 ml distilled water). 400 ml of this mixture were then placed in 500 ml Pyrex screw cap culture flasks which already contained nutrient spikes (= additions) designed to increase ambient concentrations three to six-fold. Table 7.13. provides a summary of the nutrient additions used in the bioassays. The $MgCO_3$ was added to neutralize the iron spikes which were in an acid solution in order to prevent adsorption to bottle walls (Berres and Steinnes 1975) or dissolution (Lewin and Chen 1973) prior to usage. The duplicate spiked lake water samples and non-spiked controls were incubated in the 500 ml flasks, inverted and submerged at 0.3 m in an outdoor pool at the Santa Cruz laboratory. This provided uniform temperature (27-28^{o}C) and sunlight (pool extinction coefficient was 1.5-1.7) to all flasks. To minimize light shock, all experiments were started at night.

The flasks were mixed and subsampled each evening for four or five days. A 25 ml aliquot was taken from each flask and immediately filtered on a 0.45 μm HA Millipore filter. Radioactive carbon-14 activity on the filter was measured by a thin window gas flow Geiger Müller counter.

5.2 BIOLOGICAL STUDIES

5.2.1 Phytoplankton

Water samples for phytoplankton enumeration were collected as part of the routine monitoring program on L. Yure and L. de Yojoa. Either composite samples (i.e. integrated through the euphotic zone) or discrete-depth samples were collected. In the latter case, water was taken from the same Van Dorn sample as was used to fill the primary productivity bottles. The 100 ml phytoplankton samples were preserved with Lugol's solution and stored in the dark until counting. At the beginning of the program, a manual was prepared to assist with phytoplankton enumeration and identification. This is reproduced in Appendix 8. Phytoplankton were concentrated by allowing 35 ml (L. Yure) or 50 ml (L. de Yojoa) of the sample to settle out in a Daigger settling chamber over a period of 5 days. Full details appear in Appendix 7.

Samples were examined with an American Optical inverted microscope at a magnification of X1000 or X1500. Phytoplankton identification presented some problems since a full range of taxonomic references was not available in Honduras. The principal sources used were Prescott (1979) and Patrick and Reimer (1966). In addition, early on in the program, a number of samples were identified and counted at Davis. Diagrams and color photographs of the principal species from both lakes, prepared at this time, were used for reference purposes during subsequent work carried out in Honduras.

Samples were enumerated by counting the number of cells in 100 discrete, restricted fields. Cell counts were converted to concentrations by dividing by the sample volume actually counted (= area counted on the chamber bottom X height of the water column).

Phytoplankton biomass values were estimated by assigning each species a particular geometric shape. Cellular dimensions, measured with an ocular micrometer at X1000 magnification, were then used in conjunction with the appropriate geometric formulae to calculate cell volumes which, assuming a cell density of unity, were numerically equal to cell biomass.

5.2.2 Zooplankton

During 1980 and most of 1981, zooplankton samples were taken at the lake index stations by towing a 30 cm mouth-diameter Wisconsin net (80 um mesh), from one meter above the lake bottom to the surface. Duplicate samples were always collected. A Pigmy Pattern flow meter (Kahl Scientific) attached across the net mouth enabled filtering efficiency to be estimated (by comparing meter readings resulting from a 10 m tow, with and without the net attached to the bridle). Filtering efficiency varied from about 50% to 75% (lower efficiencies resulting from increased net clogging). In mid-1981 the flow meter started to become increasingly unreliable, especially at low filtering efficiencies. For a number of sampling dates in 1981, therefore, efficiency had to be extrapolated from a curve of decreasing efficiency through time. In late 1981, the 80 um mesh Wisconsin net was replaced by a 50 um mesh Birge closing net, with a mouth diameter of 12 cm. This net had a tapering mouth collar (12-20 cm) designed to provide a filtering efficiency of approximately 100%. Comparisons between the two nets indicated that, although their relative efficiencies differed to some extent depending on the species involved, the Birge net efficiency was in the region of 100%. This value was used in all subsequent calculations. Net comparisons in L. Yure also indicated that, at least on the dates of comparison, only a few rare rotifer species (probably primarily littoral and not pelagic) were too small to be captured by the 80 um net. With the Birge net, two vertical tows were generally combined into one sample, in order to collect sufficient animals.

Zooplankton samples were preserved with 5% formalin, and subsequently examined and counted using an American Optical dissecting microscope. In those samples with very high plankton densities, it was necessary to take sub-samples for enumeration purposes. This was done by bringing the sample to a known volume (usually 50 or 100 ml), mixing it well and removing a subsample of between 1 and 4 ml with a wide-mouth automatic pipette. Usually 3 subsamples were counted from each sample. Species identifications were made using the following references: Koste (1978) (for rotifers), Ward and Whipple (1959) and Pennak (1978). Identifications of certain species were confirmed by specialists in the United States and West Germany, and through additional references listed in Hurlbert (1982).

Zooplankton biomass values were obtained, for the L. Yure samples only, by weighing a known number of individuals on a Kahn microbalance. Biomass values for rotifers were either taken from the literature or were calculated by assigning a geometric shape to the species and measuring the relevant dimensions using an inverted microscope and ocular micrometer. This work was carried out at Davis since a microbalance was not available in the Santa Cruz laboratory. Species biomass values are presented in Appendix 3.

5.2.3 Invertebrates

The series of invertebrate samples from Quebrada El Cajón was collected with a standard methodology in order to allow comparisons to be made between different sampling dates. Stones were lifted from the stream bed, with a net on the downstream side to collect any dislodged animals. All invertebrates clinging to the stones or collected in the net were removed and placed in vials containing 75% ethanol. This process was continued for exactly five minutes, with all invertebrates taken during this period being placed in the same vial. Each five minute collection period was thus equivalent to one sampling unit. Normally seven or eight such units were taken on each sampling date. Collections were always taken from the same stretch of the stream and efforts were made to sample a similar range of rock sizes on each occasion. This sampling method represents a convenient way to document relative changes in species abundance through time. It does not, however, provide an absolute measure of invertebrate density (in terms of individuals per m^2, for example). This latter would require a much more intensive sampling effort.

Species were identified to genus with the following references: Ward and Whipple (1959), Pennak (1978), Merritt and Cummins (1978), Wiggins (1977) and Edmunds et al (1976). Identifications to the species level were usually not feasible without examination of the adult stages.

Benthic invertebrates from L. Yure were collected, non-quantitatively, with an Ekman dredge and with hand-held dip nets. Animals were separated from substrate/plant material in a white plastic dish and preserved in 75% ethanol.

5.2.4. Fish

5.2.4.1 Sampling: The principal fishing gear used in the rivers was a back-pack, gasoline generator electro-shocker (Coffelt Electronics, Model BP 1-6). Sampling was carried out for a known length of time, in order to allow approximate between-date, and between-station, comparisons of fish biomass. Electroshocking was usually carried out in an upstream direction over distances of up to about 100 m at any one site. At stations sampled on more than one occasion, the same area was fished on each sampling date. A net, attached to one of the electrodes, was used to catch the stunned fish. A second person also collected fish with a dip net. Generally, all available habitat-types (pools, riffles, banks, etc.) less than about 1 m deep were sampled with the electroshocker.

In the larger rivers, gill nets were used in the dry season. They were set either diagonally across the channel or parallel to the river bank. Due to the rocky nature of most of the stream sites, seining was restricted to pools along the sides of the main river channels. (See plate 5.A). Cast nets (1/2" + 1/4" mesh) and, occasionally, small explosive charges were also used.

The back-pack electroshocker and cast nets were also used from a boat in L. Yure to sample the shore-line areas. This was a fairly effective method for collecting especially the younger age classes of the more common species.

Plate 5.A. "Tapesca" (traditional fishing weir) on Rio Sulaco near Salitrón Viejo.

Foto 5.S. "Tapesca" (presa tradicional de pesca) en el Rio Sulaco cerca de Salitrón Viejo.

The main sampling gear used in L. Yure, however, was a graded fleet of multifilament nylon gill-nets, with mesh sizes of from one to five inches (25 - 127 mm) (stretch mesh). The gill net specifications are given in Table 5.3.

Nets were generally set a few meters from the shore in water of a depth up to about 4 m. Deeper sets usually caught nothing; any fish that were caught with these sets were of the same species as those taken in shallower-water sets. Surface sets made at greater distances from the shore, likewise were very unproductive. The entire fleet was either set in sequence at one station, or was divided in order to fish two or more stations. Sets were made in the late afternoon and checked early the following morning. Fishing was usually carried out over several successive days, with the sampling station being changed each day. Initially, nets already in place were checked in the afternoon as well as the early morning. When it became clear, however, that fish were rarely being caught during the day, the sets were visited just once every 24 hours.

A number of stations in L. Yure were fished during the course of the study (See Section 11). However, because of the generally low catches (and thus the large amount of effort required to obtain adequate sample sizes), stations were not fished at random, nor was equal effort expended on each site. Sampling was concentrated in those areas which were likely to produce the best catches. These areas tended to be close to the mouths of the inflowing streams.

The size of fish caught in gill nets is usually highly dependent on mesh size. In order to estimate the selectivity of the nets used in the present study, a record was kept of the mesh size in which individual fish were caught. Selectivity data are presented in section 11.

In addition to gill-netting, samples of L. Yure fish were also obtained from several local fishermen. The person employed to carry out this work recorded the time of capture, standard length and species of the fish, removed

Table 5.3: Specifications of gill nets used in the fishing studies.
Tabla 5.3: Especificacions de las redes agalleras usadas en los estudios de peces.

Net	Length (m)	Depth (m)	Mesh Sizes (inches)*	Set	% Slack
1	43	1.8	1, 1 1/2, 2, 3, 3 1/2, 4, 5	Bottom	33
2	27	1.8	1, 1 1/2, 2, 2 1/2, 3, 3 1/2, 4	Surface	50
3	29	1.8	1, 1 1/2, 2, 2 1/2, 3, 3 1/2, 4	Surface	50
4	30	2.0	1, 1 1/2, 2, 2 1/2, 3	Bottom	50
5	30	1.8	1, 2, 2 1/2, 3, 3 1/2	Bottom	50
6	30	3.2	3, 3 1/2, 4, 4 1/2, 5	Bottom	50
7	30	3.7	1, 2, 3, 4	Bottom	50

* a) Nets were hung with approximately equal lengths of each of the component mesh sizes.

b) Mesh sizes refer to stretch-mesh dimensions and are given in inches to avoid using cumbersome metric conversions in the table.

c) Initial gill netting in L. Yure was carried out with four 30 m long nets (1,2,3,4, inch meshes). Later, when more netting was obtained, these nets were re-hung and included in those listed above.

the stomach and gonads and preserved them in 10% formalin in a labelled bottle. The fish thus sampled were all caught by hook and line and provided valuable comparative material for the gill-net samples.

Fish caught for both the lake and river studies were preserved in 10% formalin. When large numbers of a particular species were taken (by electroshocking) a subsample was preserved and the remainder was measured and returned live to the stream. There was no evidence that removal of successive samples at the most frequently sampled site (R. Yure at Yure) resulted in an appreciable reduction in fish numbers. The site was never fished very intensively, as, for example, by blocking the channel and making repeated passes across the river with the electroshocker. Furthermore, on the few occasions when the same area was sampled twice on the same day, no significant reduction in catch was noted during the later sampling effort.

5.2.4.2 Laboratory Analyses: In the laboratory, each fish was identified, weighed to the nearest 0.1 g and its standard length (total length for the eel-like *Synbranchus*) measured to the nearest 1 mm. Depending on the number of individuals in a collection, the entire sample, or a sub-sample, was then analyzed for diet and reproductive condition. Egg counts were made on mature, ripe females.

a) Diet. Stomach fullness was usually estimated on a scale of I-IV, (I = 1/10 - 2/10 full, II = 3/10 - 5/10, III = 6/10 - 8/10, IV = 9/10 - 10/10). Intestine fullness was described by the fraction of its total length which contained food. The total volume of food in the stomach was estimated by comparing food volume to solid cubes of known volumes. The cubes were a geometric series, with volumes, 1, 3, 8, 16, 27, 43, 64 ---- 1330 mm^3. Later on in the study, the cubes were replaced by hollow cylinders which allowed a more precise estimation of food volume. This method of volume estimation was chosen since it is not excessively time-consuming and is often more precise than direct measurement (by water displacement) with fish less than about 15 cm long. For larger fish, or for food volumes greater than about 1300 mm^3, volume was measured directly by submerging the food in a known volume of water contained in a graduated cylinder and noting the volume increase. Before measurement, excess moisture was removed from all food samples with a paper towel.

After estimation of total volume, stomach contents were sorted under a dissecting microscope and the various components identified to the lowest taxonomic unit possible. This was often genus in the case of fish, zooplankton, many insects and algae. However, aquatic insects were frequently too fragmented to allow a confident identification to genus level; in this case, the lowest taxonomic unit was order. This was especially so with mayfly nymphs (Ephemeroptera) and some caddis fly larvae (Trichoptera) separated from their cases. Once stomach contents had been sorted and identified, the volume of each component was estimated by the method already described. Where entire, or almost entire, animals were present, their number was noted. However, this information was not especially useful on a comparative basis because of variation in the type, size and degree of fragmentation of the diet components.

Food present in the intestine was only analyzed for those species (mainly Cichlasoma spp.) in which components could be easily distinguished. No attempt was made to measure to volume of intestinal food items, because of their poor state of preservation. Instead, components were visually ordered on a scale of dominance (I indicating the most abundant item). Occasionally, this same method was also used for the description of stomach contents.

b) Reproductive Condition. The gonads of all fish analyzed were weighed to the nearest 0.01 g on a Mettler balance. A gonad development index was established for use with cichlid species. It distinguishes the following maturity stages:

Stage	♀♀	♂♂
I	Eggs very small and clear	Testes thread-like and clear
II	Some (< 1/2) eggs opaque; ovaries small	Testes thin, opaque white
III	Most (> 2/3) eggs opaque; difficult to separate just visible to naked eye	Testes enlarged
IV	Ovaries large; eggs opaque yellow color, large; do not separate easily	Testes very large
V	Eggs golden yellow, translucent; separate easily	Milt extruded
VI	(Spent -- in Cichlasoma, spent females are often difficult to distinguish, because another batch of eggs are already developing. Spent males are more easily distinguished, the testes giving the appearance of deflated sacs).	

The stages of this maturity index are more clearly defined for female cichlids than for the males. Stages are similar to those of Nikolsky's (1963) index.

Gonado-somatic indices (G.S.I.) were calculated with the following formula:

$$G.S.I. = \frac{G}{W} \times 100$$

where G = weight of gonads (g)

and W = weight of fish (g)

Oocyte diameters were measured at 10X or 30X magnification with an ocular micrometer. In some maturing and all mature ovaries, 30-50 oocytes were measured. Only those oocytes larger than 0.4 mm were included in size frequency determinations, since smaller oocytes show little if any yolk development. With ovaries containing mainly small, immature oocytes, the diameter of only the largest size class were measured. Mature cichlid eggs are not spherical but ovoid, and so the length and width of these eggs were measured.*

Dry weights of mature eggs were measured by placing replicate groups of a known number of eggs (usually 10 for species with large eggs, 20-40 for species with small eggs) in pre-weighed aluminum dishes, and drying at 60°C until a weight change of less than 1% was attained.

Egg counts were made as follows. In cichlid species, which have relatively few, but large, eggs, the total number of mature eggs in one or both ovaries was counted. With counts from just one ovary, the weights of each ovary were used to estimate the total number of eggs in both ovaries. In other species, with smaller eggs, counts were made by sub-sampling by weight. Three or more subsamples, taken from previously weighed ovaries, were weighed and the number of eggs in each counted. In species whose ovaries are enclosed in relatively thick membranes, e.g. bass, all the eggs were separated from the membranes and re-weighed before being sub-sampled.

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*The formalin used for sample preservation contained two phosphate salts which acted to reduce egg shrinkage. The formula for this formalin/salt mixture is as follows (de Vlaming, personal communication):

$NaH_2PO_4 \cdot H_2O$	.19g	Formalin (conc.)	110 ml
$Na_2H\ PO_4$	.51 g	Water	1000 ml
NaCl	4.25 g		

An alternative to formalin for preserving ovaries is Gilson's fluid, which has the double advantage of hardening the eggs and separating them by breaking down ovarian tissue. Gilson's fluid is a mixture of the following ingredients (Ricker 1971):

100 ml	60% alcohol	18 ml	glacial acetic acid
880 ml	water	20 ml	mercuric chloride
15 ml	80% nitric acid		

Although this preservative was infrequently used in the present study, it has often been employed by other researchers. It is probably preferable to formalin for bass ovaries, but is unnecessary for cichlid ovaries owing to the ease with which mature eggs can be separated from each other in this group.

c) Fat: The amount of fat present in the abdominal cavity of all fish examined was visually estimated. Indices describing the degree of fat accumulation were established for the more common species. These are summarized below:

Cichlasoma
0. No obvious fat accumulation
1. Thin strip of fat along intestine
2. Thicker strip (> 1/2 diameter of intestine)
3. Thick strip along intestine is extended into mesenteric-like sheets covering posterior end of intestine.
4. Fat covering intestine and stomach

Rhamdia
0. No obvious fat accumulation
1. Thin strip of fat along posterior part of intestine.
2. Thin strip along intestine and around stomach.
3. Medium strip along intestine and around stomach.
4. Thick strip over intestine and stomach
5. Fat covers intestine and stomach.

Micropterus

	Pyloric Caecae:	Intestine:
0.	No fat	No fat
1.	Thin strips between caecae	Thin strip
2.	Thin layer over caecae	Medium strip
3.	Medium layer over caecae	Medium layer
4.	Thick layer over caecae	Thick layer

(Index components values were summed to give one compound value per individual).

Astyanax
0. No obvious fat accumulation
1. Thin strip along intestine
2. Thin layer over caecae and medium strip along intestine.
3. Medium layer covering intestine and caecae
4. Abdominal cavity full of fat.

5.2.4.3 Growth Rates: Three methods were used to estimate growth rates of some of the more common species in the El Cajón area. All three methods were not applicable to all the species considered and all have certain problems of interpretation.

a) Tagging. This method was used for the L. Yure cichlid, *Cichlasoma motaguense* ("guapote"). Guapote were captured around the perimeter of the reservoir by electroshocking (this method of capture does not produce adverse medium or long-term effects on this species, although it does on bass, for example). Fish were maintained in large, shaded, plastic bowls until about 30 individuals had been caught. The standard length of each fish was then measured to the nearest 1 mm and a small, numbered, plastic fingerling tag (Floy Tag and Manufacturing, Inc.) was attached by insertion of a vinyl thread through the dorsal musculature, between the second and third spines of the dorsal fin. (Tagged fish had previously been kept in an outdoor pool at the laboratory for several weeks without any signs of adverse effects resulting from this tagging procedure).

Tagged fish were released back into the lake near the point of capture. A reward system was established so that fishermen who subsequently caught any of the tagged fish would return them to an assistant at the lake. The recovered fish were preserved in 10% formalin and soon thereafter measured (before any formalin-induced shrinkage could occur). They were also examined for any signs of infection or other abnormalities.

b) Cohort Analysis. This method of estimating growth rates can only be used where all, or most of the reproduction by a species occurs during a relatively short period of the year. As the size frequency distribution of a population is monitored through time, the standard length corresponding to a year class peak (for example, the young produced during the last period of reproduction) gradually increases as the fish grow. The rate at which this peak length increases through time represents the average growth rate of that year class (cohort). Of the fish species studied in the El Cajón area, only two were suitable for cohort analysis, *Cichlasoma spilurum* ("congo") and *Rhamdia cabrerae* ("bagre"). Cohort analysis can represent a valuable tool in fisheries management and, together with some of the assumptions involved in its use, will be further discussed in section 11.

c) *Scale Analyses*. Many species of fish produce markings, called growth checks, on scales, vertebrae, otoliths or other hard parts. In temperate species these growth checks are often formed during periods of slower or zero growth, for example, during periods of low temperature or poor food supply. If such checks are laid down annually on a regular basis, they can be used for aging a fish and, from a knowlege of the relationship between fish length and scale diameter, for back-calculating its growth rate. Growth checks were observed on several species from the El Cajón area, particularly *Cichlasoma* spp. Scale samples were routinely collected from these species in an effort to determine at which time in the year growth checks were being formed. It is essential that time of check formation be adequately documented before scales or other hard parts are used for age and growth rate determinations. It is also necessary for scales always to be taken from the same part of the fish, although the actual area chosen will vary between species. Scales removed from the sampling area ideally should have clear checks, be of uniform size and shape, and include few regenerated scales. After removing the scales, they were stored inside a small envelope, on which were recorded the species of fish, its standard length, weight, size and maturity, and the date, time, place and method of capture. Scales were subsequently dry mounted between two glass microscope slides and examined under a dissecting microscope or using an adapted microfiche reader. Using a calibrated ocular micrometer or a rule, the distances between the center, or focus, of the scale and each growth check and the outer edge of the scale were measured. Further discussion of the method of calculating growth rates from scale measurements is deferred to section 11.

6. RIVER WATER QUALITY

6.1 INTRODUCTION

The drainage basin of the Humuya, Sulaco and Yure rivers covers an area of about 8320 km^2, with the Sulaco watershed representing approximately 56% of the total area. Elevations within the drainage basin range from 100 m.a.s.l. to 2,400 m.a.s.l. The river valleys are V-shaped, with 35% of the area of the Humuya watershed having a slope of more than 40%. The equivalent value for the Sulaco watershed is 65% (COHDEFOR 1980).

Before vegetation clearance was started in the reservoir basin, approximately 38% of the area below 300 m.a.s.l. was forested, mainly with pine, *Pinus oocarpa*, and oak, *Quercus oleoides*. Land used for some form of agriculture has been estimated as comprising about 42% of the area below the 300 m contour (COHDEFOR 1980). Intensive agriculture, however, is almost non-existent in this area.

Below the dam site, the R. Humuya joins the R. Ulúa and flows over the alluvial deposits of the Sula valley. Approximately 26% of the valley is under cultivation and 46% is represented by pasture and fallow land. The R. Ulúa supplies water for much of the banana and sugar cane plantations located in the Sula valley. (Note that, in this report, the stretch of river between the El Cajón dam site and the Ulúa confluence is called the R. Humuya, in order to avoid introducing a third name [R. Comayagua]).

The present section discusses the river water quality data collected from a total of 18 stations (including the L. Yure tributaries), both within the El Cajón watershed and downstream from the dam site. All the data are presented in Tables A2.1-19 (Appendix 2). Fig. 6.1 summarizes much of this information by presenting mean dry season (January - April) and mean wet season (June - September) values of each water quality parameter at most of the sampling

Figure 6.1: Mean dry season (January - April) and wet season (June - September) values of river water quality parameters.

Figura 6.1: Valores promedios de los parámetros de calidad del agua fluvial en las estaciones seca (enero - abril) y lluviosa (junio - septiembre).

(Open histograms represent dry season values, shaded histograms represent wet season values.)

<u>Station</u> <u>key</u>:

A. R. Sulaco at Victoria

B. R. Humuya at Comayagua

C. R. Chiquito

D. R. Humuya at Ojos de Agua

E. R. Humuya at Sulaco confluence

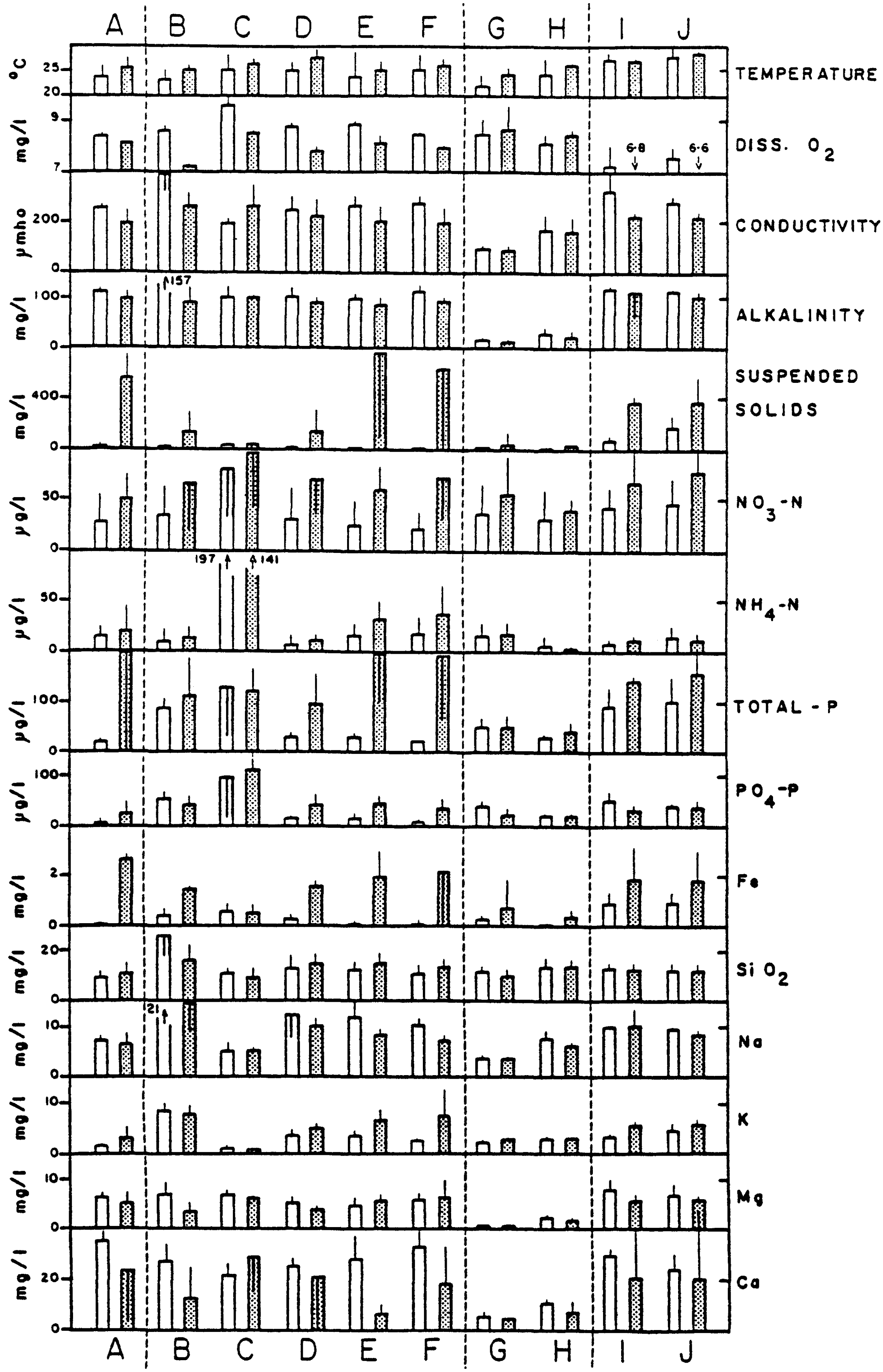
F. R. Humuya at El Cajón

G. R. Yure at Yure

H. R. Yure at Humuya confl.

I. R. Humuya at Santa Rita

J. R. Ulúa at Guanacastales


A B C D E F G H I J
TEMPERATURE
DISS. O_2
CONDUCTIVITY
ALKALINITY
SUSPENDED SOLIDS
NO_3-N
NH_4-N
TOTAL - P
PO_4-P
Fe
SiO_2
Na
K
Mg
Ca
°C
mg/l
µmho
µg/l
6·8
6·6
157
197
141
21

stations. Seasonal fluctuations in selected parameters are shown in more detail in Figs. 6.2-6.4.

Before comparing patterns at different stations, it should be emphasized that, with a sampling frequency of once per month, seasonal trends may be distorted by weather conditions, such as extreme storm events. Thus care must be taken when interpreting some of the present water quality data. In addition it should be noted that, in Figs. 6.2-6.4, lines joining individual data points do not necessarily represent the trajectories of the parameter between sampling dates. This is especially so for stations sampled monthly. Curves, rather than histograms, are presented for purposes of clarity.

The following discussion treats each parameter in turn and concludes with a comparative summary of river water quality.

6.2 RESULTS

6.2.1 Temperature

Trends in water temperature were very much as expected. Temperatures were generally higher during the months of April-August, and tended to lag behind the curve of incident solar radiation (Fig. 7.6a). In the Humuya and Ulúa rivers, seasonal temperature variation increased with decreasing elevation. For example the range in observed temperatures was 4.0°C at Comayagua and 5.7°C at Ojos de Agua. Below the dam site, the range at San Manuel was 5.6°C and at Guanacastales 7.2°C. Both minimum and maximum temperatures tended to increase in a downstream direction. On any one day, the difference in the temperature of the Humuya between Comayagua and Ojos de Agua was between about 0.4 and 1.8°C. Between San Manuel and Guanacastales, the temperature difference varied from 0.4-3.7°C. There was a 1-2°C warming of R. Yure water between the village of Yure and the Humuya confluence.

Figures 6.2 (a-d) Seasonal variation in river quality , El Cajón watershed stations.

Figuras 6.2 (a-d) Variación estacional la calidad de agua fluvial para las estaciones de la cuenca de El Cajón.

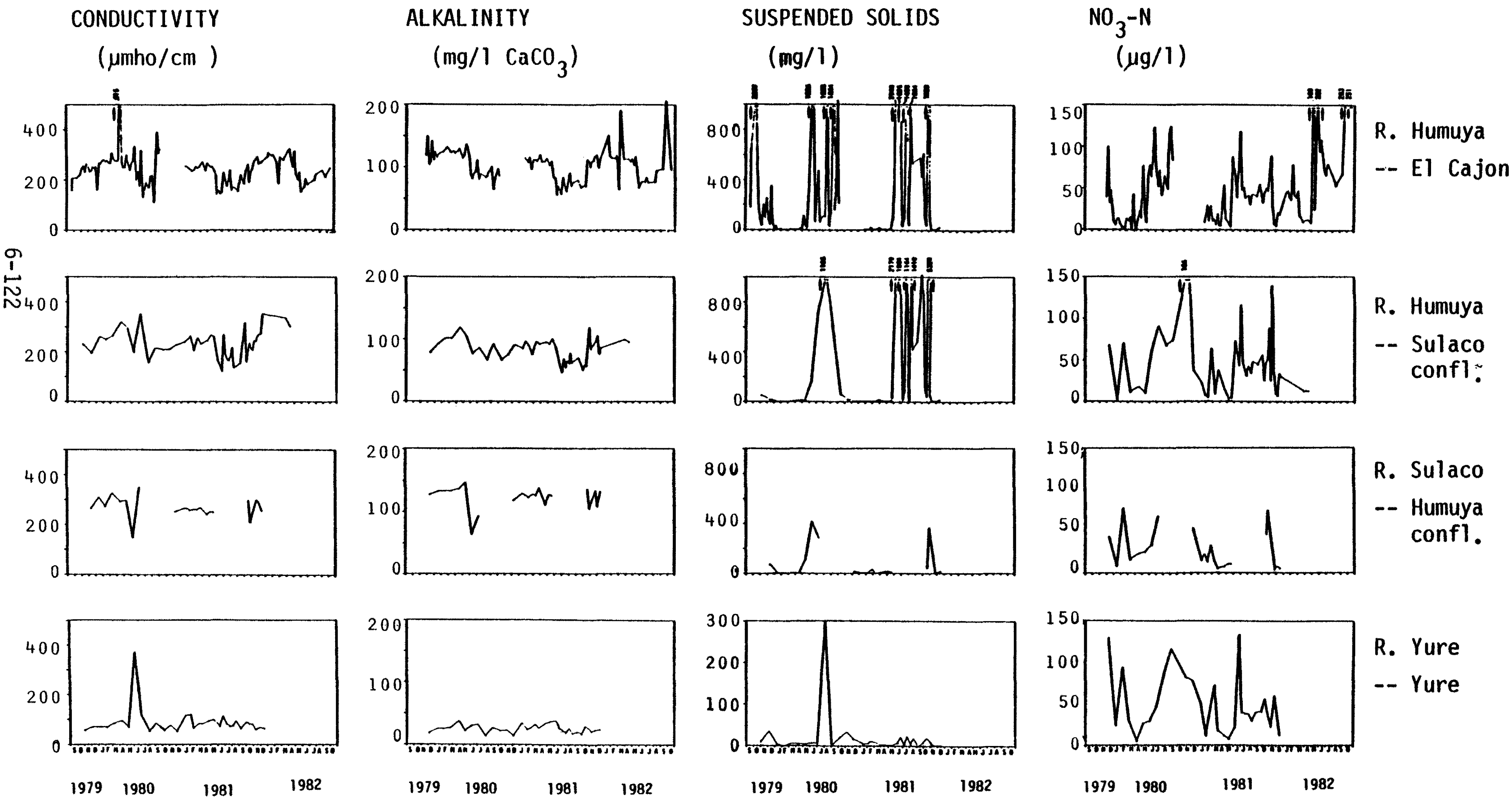

CONDUCTIVITY
(μmho/cm)
ALKALINITY
(mg/l $CaCO_3$)
SUSPENDED SOLIDS
(mg/l)
NO_3-N
(μg/l)
R. Humuya
-- El Cajon
R. Humuya
-- Sulaco confl.
R. Sulaco
-- Humuya confl.
R. Yure
-- Yure
1979
1980
1981
1982

Figure 6.2 a)

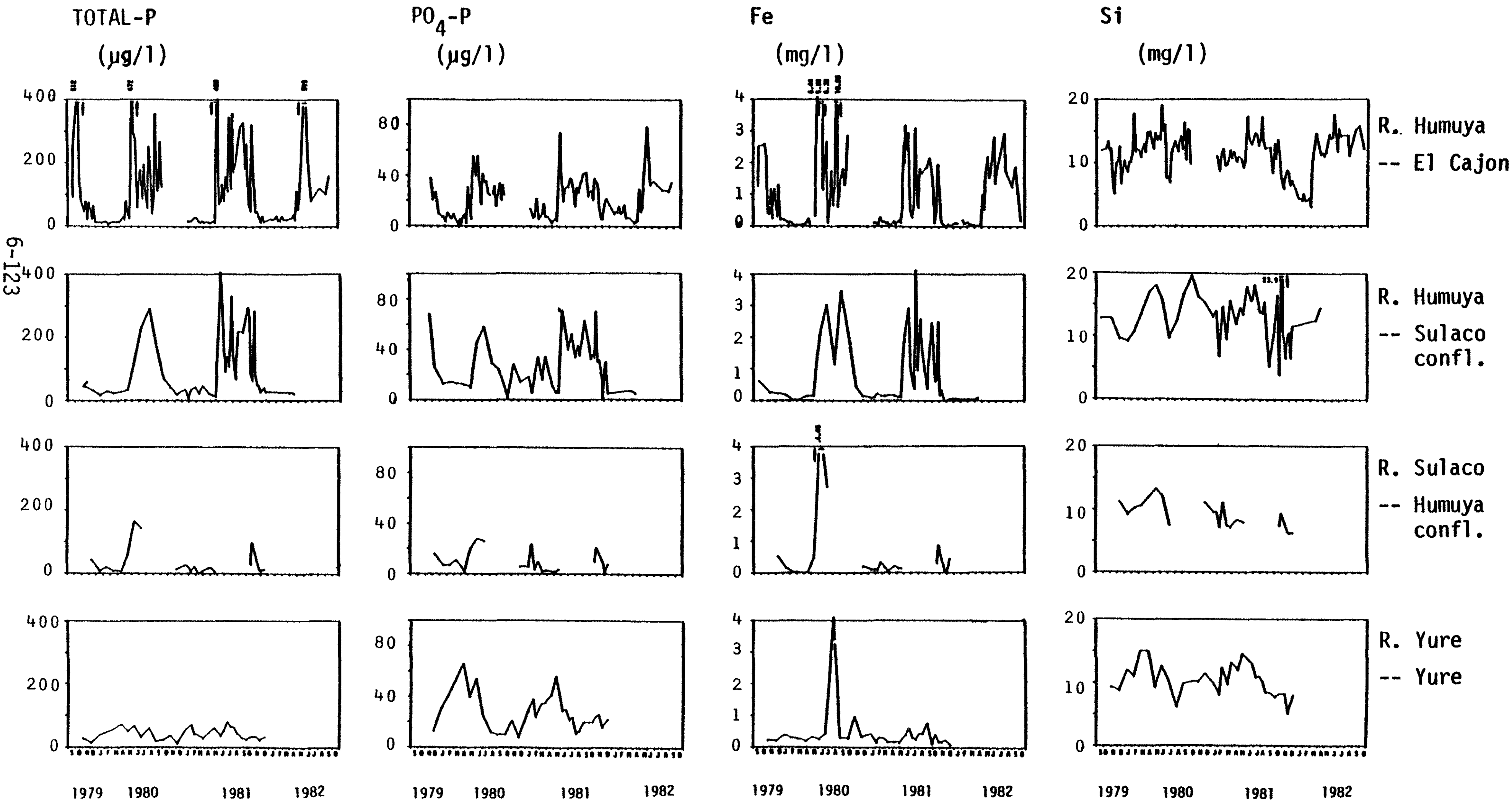
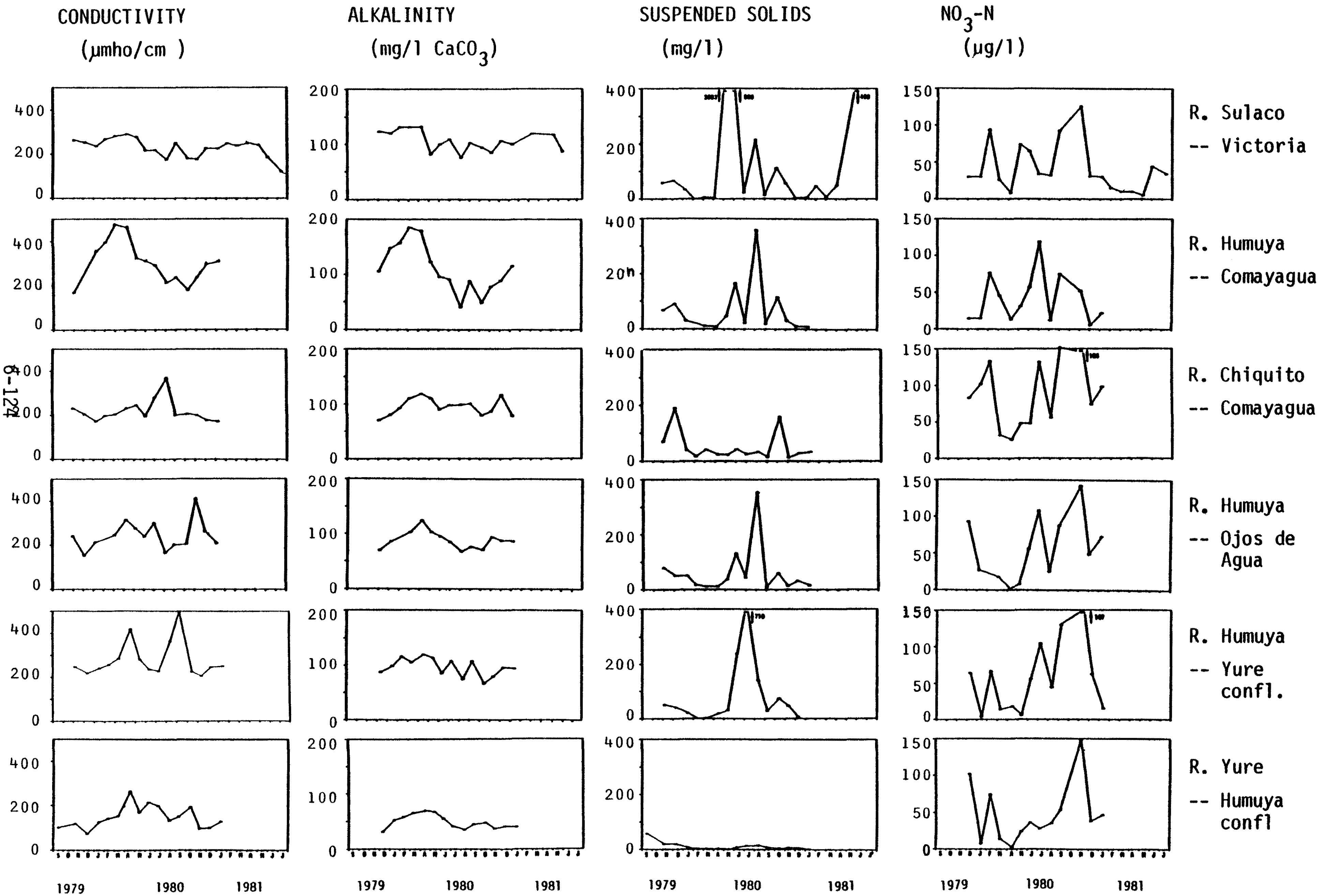

TOTAL-P
(µg/l)
PO_4-P
(µg/l)
Fe
(mg/l)
Si
(mg/l)
R. Humuya
-- El Cajon
R. Humuya
-- Sulaco confl.
R. Sulaco
-- Humuya confl.
R. Yure
-- Yure
1979
1980
1981
1982

Figure 6.2 b)



CONDUCTIVITY
(µmho/cm)
ALKALINITY
(mg/l CaCO3)
SUSPENDED SOLIDS
(mg/l)
NO3-N
(µg/l)
R. Sulaco
-- Victoria
R. Humuya
-- Comayagua
R. Chiquito
-- Comayagua
R. Humuya
-- Ojos de
Agua
R. Humuya
-- Yure
confl.
R. Yure
-- Humuya
confl
1979
1980
1981

Figure 6.2 c)

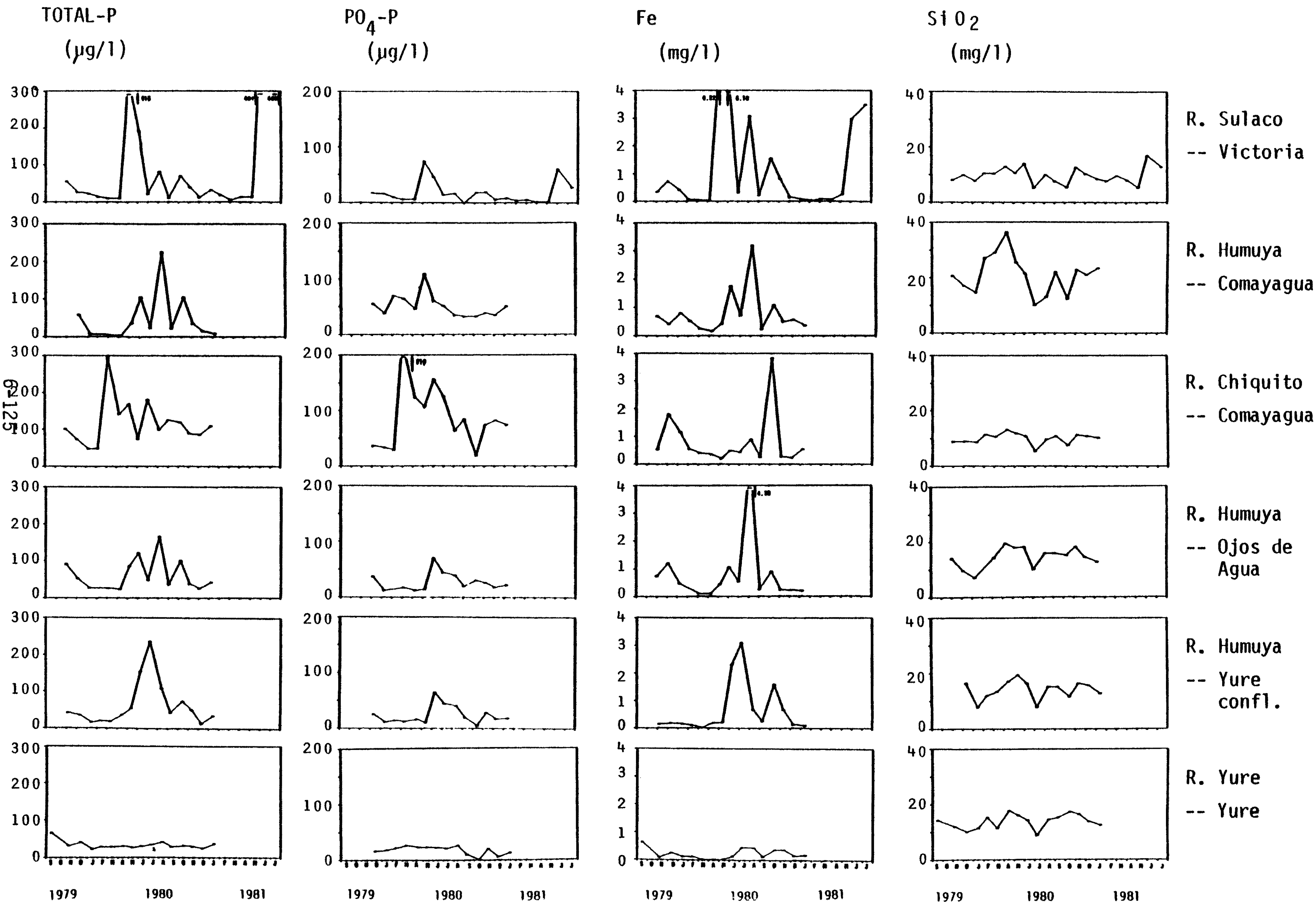

TOTAL-P
(µg/l)
PO4-P
(µg/l)
Fe
(mg/l)
Si O2
(mg/l)
R. Sulaco
-- Victoria
R. Humuya
-- Comayagua
R. Chiquito
-- Comayagua
R. Humuya
-- Ojos de Agua
R. Humuya
-- Yure confl.
R. Yure
-- Yure
1979
1980
1981

Figure 6 2 d)

Figures 6.3 (a-b) Seasonal variation in river water quality, R. Humuya and R. Ulua, downstream from El Cajón dam site.

Figuras 6.3 (a-b) Variación estacional en la calidad del agua fluvial en el R. Humuya y R. Ulúa, río abajo de El Cajón.

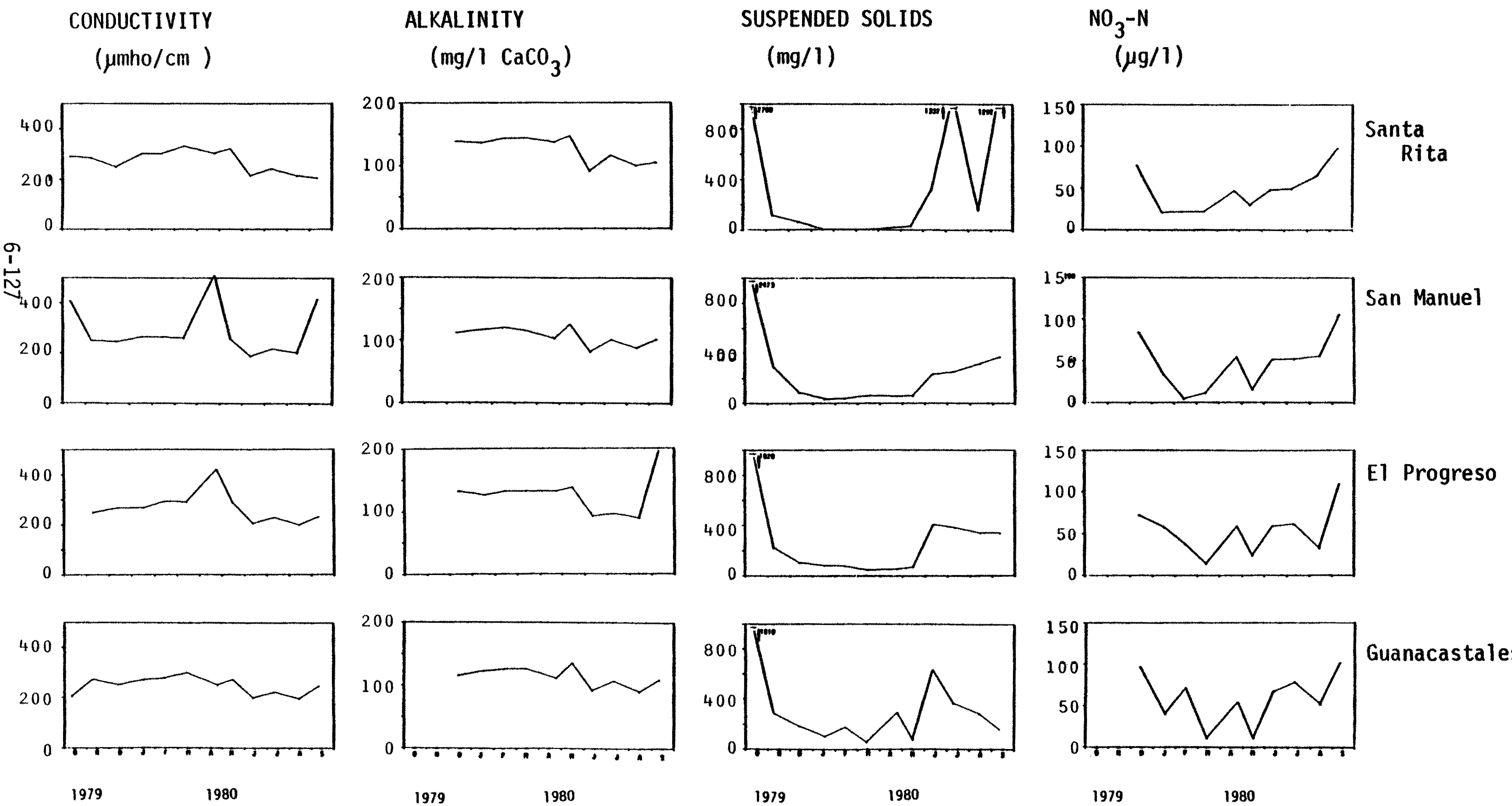

CONDUCTIVITY
(μmho/cm)
ALKALINITY
(mg/l CaCO3)
SUSPENDED SOLIDS
(mg/l)
NO3-N
(μg/l)
Santa Rita
San Manuel
El Progreso
Guanacastales
1979
1980

Figure 6.3 a)

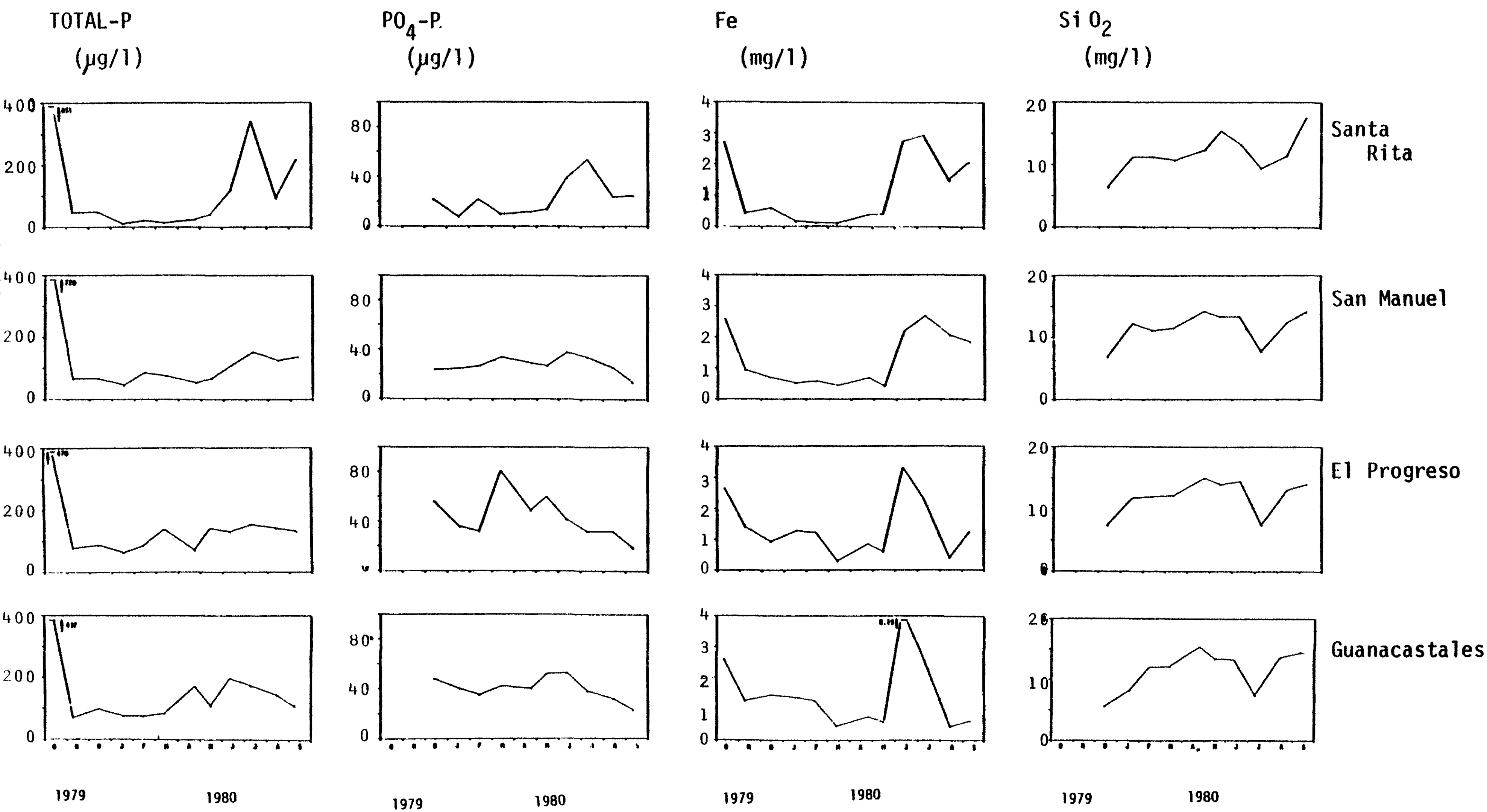
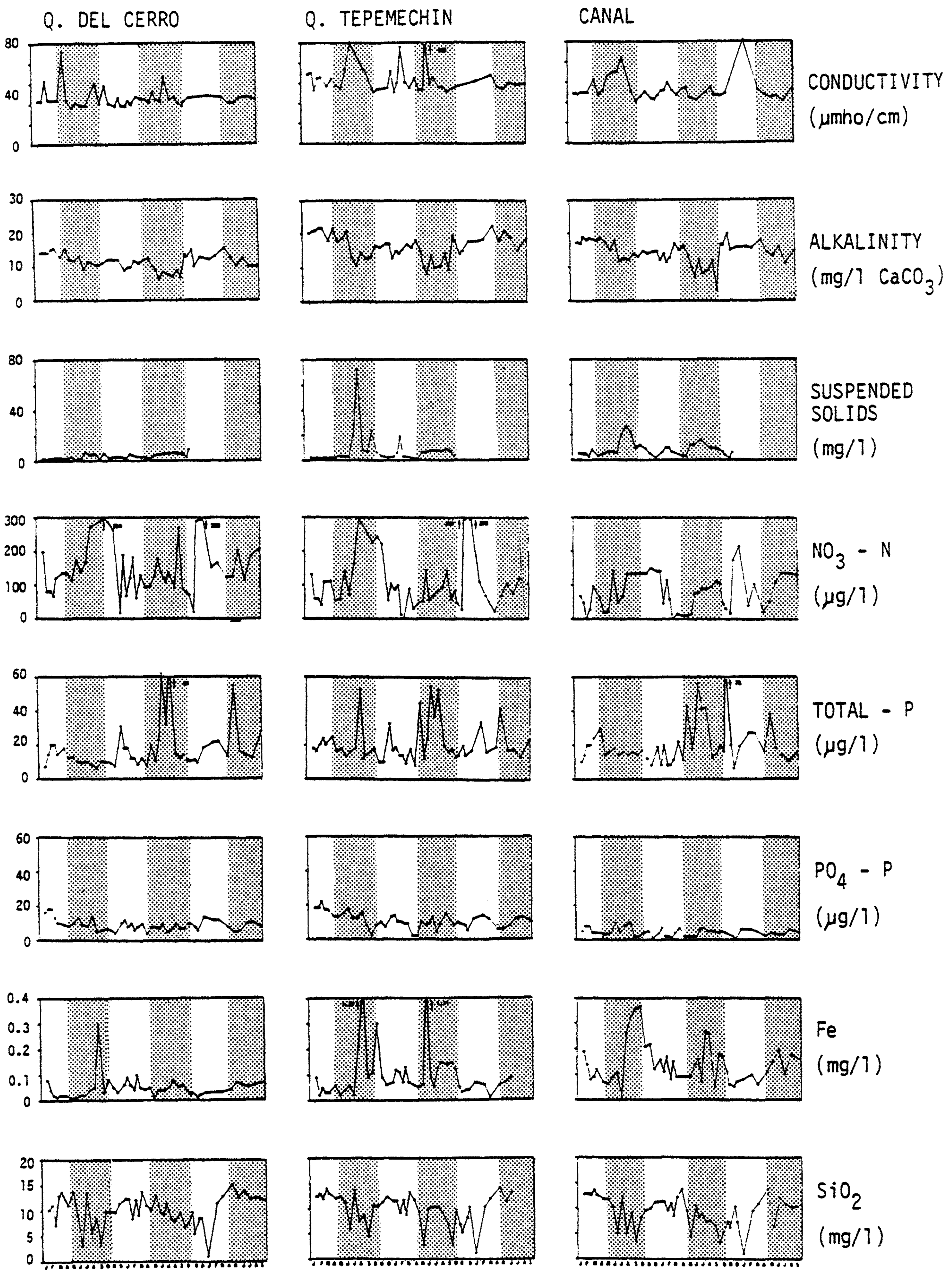

TOTAL-P
(μg/l)
PO_4-P
(μg/l)
Fe
(mg/l)
Si O_2
(mg/l)
Santa Rita
San Manuel
El Progreso
Guanacastales
400
200
0
80
40
4
3
2
1
20
10
1979
1980

Figure 6.3 b)

Figure 6.4: Seasonal variation in river water quality, L. Yure tributaries.

Figura 6.4: Variación estacional en la calidad del agua lluvial de los tributarios en el L. Yure.



Q. DEL CERRO
Q. TEPEMECHIN
CANAL
CONDUCTIVITY (µmho/cm)
ALKALINITY (mg/l $CaCO_3$)
SUSPENDED SOLIDS (mg/l)
NO_3 - N (µg/l)
TOTAL - P (µg/l)
PO_4 - P (µg/l)
Fe (mg/l)
SiO_2 (mg/l)
1980
1981
1982

6.2.2 Oxygen

Although dissolved oxygen concentrations tended to be somewhat lower in the wet season than in the dry season (Fig. 6.1), this was principally because of the higher water temperature during the months of May - August, (the solubility of oxygen being inversely related to temperature). On nearly all the sampling dates at every station, river water was more than 90% saturated with oxygen. Even in the R. Chiquito, downstream from the waste-water discharge during periods of low flow, oxygen levels remained high.

6.2.3. Conductivity

The conductivity of water at a given temperature is usually related to the amount of dissolved matter it contains (the exact relationship depends on the composition of the dissolved fraction). All conductivity values in this report have been standardized by correction to 25^{o}C.

The general seasonal trend in conductivity was for an increase in conductivity between November and April and a decrease between May and September. During the wet season, much of the water entering rivers is surface runoff and relatively dilute (in terms of the major cations and anions). However, during the dry season, most water percolates through the soil and enters a watercourse as subsurface or groundwater runoff, which tends to increase its content of dissolved matter.

The greatest fluctuation in conductivity between the wet and dry season was observed for the R. Humuya at Comayagua. The seasonal pattern was not so distinct at Ojos de Agua or at the Yure confluence, but at all three stations peak conductivities were more than twice the lowest values. Less variation was apparent, however, with the R. Sulaco at Victoria. (See plate 6.B). It is possible that this was simply an artifact of sampling frequency, but nevertheless probably did represent a real phenomenon. It can be noted, for

Plate 6.B. Rio Sulaco at Victoria.
Foto 6.B. Rio Sulaco en Victoria.

Plate 6.C. Sampling station, Rio Yure at Yure.
Foto 6.C. Estacion de muestreo en el Rio Yure en Yure.

example, that the variation in conductivity of the R. Humuya was lower below its confluence with the R. Sulaco than above it (Fig. 6.2a) even though more frequent sampling at the dam site would have been expected to better document variation at this station. This suggests that inflowing Sulaco water damped down the conductivity fluctuations of the Humuya. (The anomalously high conductivity values in April 1980 and June 1980 at El Cajón and R. Yure at Yure, respectively, are probably not real but represent meter malfunctions).

Superimposed on the dry-wet season trend in conductivity, a number of records (e.g. El Cajón, Victoria) demonstrate a small rise in conductivity between July and August. This was presumably related to the normal reduction in precipitation at that time of year (Fig. 7.5).

The conductivity of the Yure river was lower than that of the Humuya and Sulaco, with values ranging from 60 to 100 umho/cm at Yure and demonstrating a slight trend towards a dilution of the water in the wet season. (See plate 6.C). By the time the R. Yure joined the Humuya, its conductivity had increased to between 100 and 200 umho/cm. The normal pattern of seasonal fluctuation was more evident at the downstream station, with conductivities gradually increasing between December and April and, rather irregularly, decreasing through the wet season.

The four stations below the El Cajón dam site exhibited generally similar conductivities to those of the Humuya and Sulaco rivers (Fig. 6.3). Values again were somewhat lower from June to September. The April peaks in conductivity at San Manuel and El Progreso were probably unrelated to that occurring at El Cajón a few days previously. Differences in the records of San Manuel and Santa Rita, however, probably reflect the influence of the Ulúa river which joins the Humuya below Santa Rita.

6.2.4 pH

pH at all stations was usually between 7 and 8 and showed no obvious seasonal variation (Table 6.4, Appendix 2). There were also no consistent differences between upstream and downstream stations, for example, Comayagua and Ojos de Agua on the R. Humuya. The fluctuations in pH observed in the Yure drainage, for example at Yure and the Lago Yure tributaries, were of similar magnitude to those seen in the Humuya and Sulaco rivers, even though the lower alkalinity of the R. Yure would indicate a reduced buffering capacity in this river.

6.2.5 Alkalinity

The alkalinity of water refers to the quantity of dissolved material present which acts to increase the pH, i.e. to make the water more alkaline. In most inland waters, bicarbonates, carbonates and hydoxides are the principal contributors to alkalinity although borates, silicates and phosphates may also contribute. The equilibrium between carbonate, bicarbonate and free (dissolved) carbon dioxide is the system which provides most of the buffering in freshwaters, i.e. it acts to resist changes in pH. Thus alkalinity is a parameter of considerable importance in limnological studies.

During the present study, total alkalinity was routinely measured and results are presented in terms of mg/l $CaCO_3$. That is, alkalinity deriving from $CO_3^{=}$, HCO_3^- and OH^- was grouped together and expressed as though it were all $CaCO_3$. (In fact, at the pH's generally encountered in the El Cajón watershed, nearly all the alkalinity would have come from bicarbonate rather than carbonate).

Since bicarbonate/carbonate are usually the major anions in freshwaters and alkalinity is mainly determined by these compounds, a strong relationship is usually to be expected between total alkalinity and conductivity. This proved to be true with the rivers of the El Cajón watershed, where seasonal fluctuations in alkalinity closely followed those in conductivity.

The most detailed record, from the dam site station (Fig. 6.2a) shows a rather precipitous drop in alkalinity at the beginning of the wet season, (May or June) in each of the three years of this study. After this initial drop, alkalinities tended to remain at fairly uniform, low levels through the wet season, before rising again in October-November. The data from El Cajón demonstrate well that, although there was considerable fluctuation in river discharge during the wet season, alkalinity, like conductivity, responded only slightly to this within-season variation. A similar example is seen with the R. Yure at Yure. Flow on 6 August, 1980 was over ten times "normal" discharge rates, but alkalinity (and conductivity) were reduced by 50% at most.

A comparison of the dry season records for the Humuya and Sulaco rivers at their confluence shows that Sulaco water had a higher alkalinity (about 170 mg/l $CaCO_3$ compared to about 100 mg/l for the Humuya). Not surprisingly, values at the dam site were intermediate.

The difference between dry and wet season alkalinity values was greatest at Comayagua on the R. Humuya. Variation was much reduced downriver at Ojos de Agua, however.

The alkalinity of the Yure system was considerably lower than that of the Humuya and Sulaco, ranging from about 10 mg/l $CaCO_3$ in the L. Yure tributaries (formerly the headwaters of the R. Yure), to 30 mg/l at the Yure station, to about 50 mg/l at the Humuya confluence (Figs. 6.2 and 6.4). The normal seasonal variation was evident at all three sites with the sudden June/July drop in alakalinity being especially obvious at the upper two sites.

6.2.6 Suspended Solids

There is often no simple relationship between the turbidity of a water sample and the concentration of suspended matter it contains, since the particles contributing most to turbidity may not be those representing the major component (by weight) of suspended solids (APHA 1975). Nevertheless, for the present purposes there is an obvious positive correlation, of some form, between suspended solids concentration and turbidity (Tables A2.1-19). Only the former will therefore be discussed in this section.

The very great short-term fluctuations in the suspended solids concentrations of the R. Humuya during the rainy season are obvious from inspection of Fig. 6.2a. Highest concentrations were observed at the beginning and end of the wet season. (See plate 6.D). Peak concentrations observed in the R. Humuya at El Cajón and just above the Sulaco confluence were 3020 and 5320 mg/l respectively. The difference between wet and dry seasons was even greater when loadings (sediment concentration x river discharge) are considered instead of concentrations (Fig. 6.5a). Discharge at the dam site station was estimated by summing the flows of the Humuya and Sulaco rivers just above their confluence. These in turn were calculated from ENEE gauge readings (at Piedra Parada and Los Naranjos). The maximum observed daily loading rate of suspended matter at El Cajón was 286,000 tonnes/day (286×10^9 g), in September 1980. This value was almost certainly greatly exceeded, however, during the record flood of May 1982. Unfortunately, no suspended solids analyses are available from that event.

Particulate matter concentration is often related to river discharge as: $C = aQ^b$, where C = concentration, Q = discharge rate and b and a are coefficients. For the R. Humuya at El Cajón, the specific relationship was $C = 0.106\ Q^{1.490}$ ($R^2 = 0.71$). The relatively high variance associated with this relationship, together with the nature of the power function mean, however, that it is of limited use in terms of predicting sediment loading.

Since the dam site station was usually sampled at fixed weekly intervals,

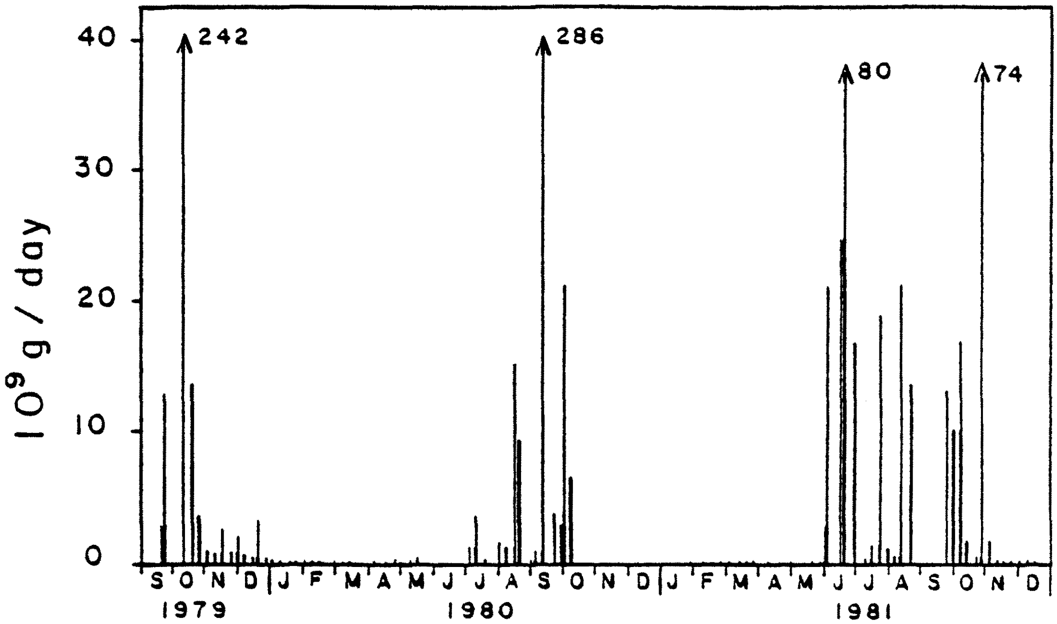
Plate 6.D. Rio Humuya, just above confluence with the Rio Sulaco.

Foto 6.D. Rio Humuya, antes de la confluencia con el Rio Sulaco.

Plate 6.E. Rio Yure (foreground) at the confluence with the Rio Humuya (background). (September 1982).

Foto 6.E. Rio Yure (abajo) en la confluencia con el Rio Humuya (arriba). (Septiembre 1982).

(a)



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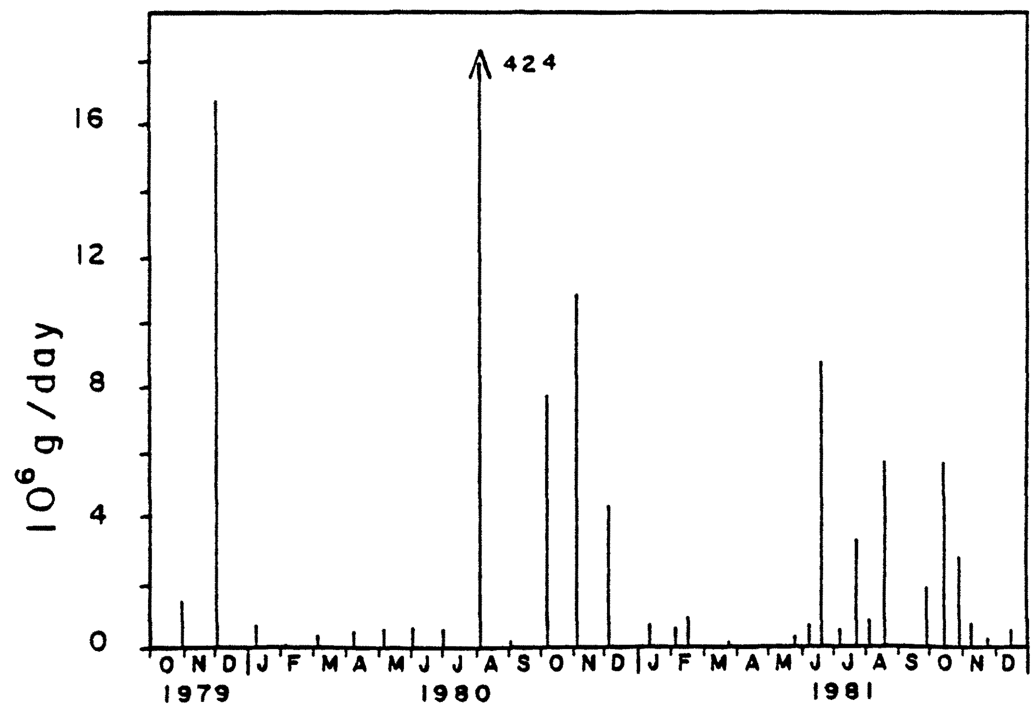


Figure 6.5: Suspended solids loading for (a) R. Humuya at El Cajón and (b) R. Yure at Yure, 1979-1981

Figura 6.5: Sólidos suspendidos acareados por (a) R. Humuya en El Cajón, y (b) R. Yure en Yure, 1979-1981.

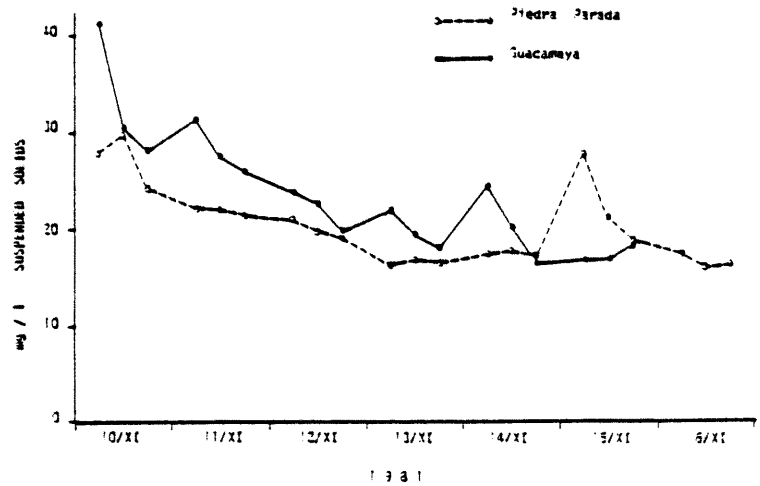
an average loading rate calculated from the 3-year data base can probably be used with some confidence to estimate total annual sediment loading at El Cajón. That is, the river was probably sampled sufficiently regularly to provide a representative series of suspended solids concentrations, even though many floods were undoubtedly "missed" with the weekly sampling schedule. It is obvious from Fig. 6.5 that nearly all the sediment loading at El Cajón occurs between May and October. During these months, the mean daily loading rate, from 1979 to 1981, was 20.13×10^9g/day. The average annual loading rate was therefore 3704×10^9g (20.13×10^9g/day x 184 days), or 3.7 million tonnes. This value is well within the range of 1-8 million tonnes per year estimated by Motor Columbus (1977) to be the "normal" variation in sediment loading rate. The present estimate of 3.7 million tonnes per year is actually an underestimation of the total amount of sediment carried by the river, since it includes only the wash load and not the bed load. Although bed load often represents a small proportion of the wash load (Dance 1981), it can be as high as 50% during extremely high flow periods (e.g. Likens et al. 1977).

Because of the very rapid fluctuations in suspended solids concentrations, it is difficult to meaningfully compare watershed stations which were sampled at monthly intervals. The R. Yure, however, was distinctive, in that it always carried relatively low sediment loads. Concentrations of suspended solids in the R. Yure were very similar at both upstream and downstream stations (Fig. 6.2). The seasonal loading pattern of this river at Yure (Fig. 6.5b) was dependent primarily on the fluctuations in river discharge since sediment concentrations were relatively constant through the year. (See plate 6.E). However, the importance of single, extreme storm events is illustrated in Fig. 6.5b, where an approximately 16-fold increase in stream discharge resulted in a 40-fold increase in sediment loading rate. Assuming an average daily loading rate of 2.1 tonnes/day (over the whole year), the sediment load on 6/VIII/80 represented 55% of the total loading for the remainder of the year (364 days).

During November 1981 and September 1982 a study was carried out to investigate the relative loading rates of suspended solids at two stations on the R. Humuya. One of these, Guacamaya (near Ojos de Agua), represented the future upper limit of the Humuya branch of the El Cajón reservoir. The second station, Piedra Parada, was just above the Humuya's confluence with the Sulaco. The difference in sediment loading between these two stations, over a given period of time, represents an estimate of the amount of suspended matter entering the future reservoir-section of the R. Humuya from its "immediate" watershed, i.e. the area north of Ojos de Agua. Fig. 6.6a-b shows the suspended solids concentrations and loading rates at both stations in November 1981. Fig. 6.6c is a graph of suspended solids concentrations over a period of 14 days in September 1982. (Unfortunately, reliable gauge readings at one of the stations were not available during half of this period, so loading rates could not be calculated).

Concentrations of suspended matter were similar at both of the aforementioned stations, and the influence of storm events was obvious. Because of the increase in river discharge between Guacamaya and Piedra Parada, however, sediment loading rates at the downstream station were approximately twice those at the upstream station. Thus, over that stretch of the Humuya river which will form one of the principal branches of the El Cajón reservoir, a distance of about 43 km, the total amount of suspended material carried by the river increased by between 50 and 100% (in November 1981, at least). The catchment area of the R. Humuya above Ojos de Agua is 2576 km^2. That between Ojos de Agua and the Sulaco confluence is 1102 km^2. The increase in sediment loading between these two points is therefore in rough agreement with the relative increase in the drainage area of the river, and suggests that the areal erosional rate is

(a)



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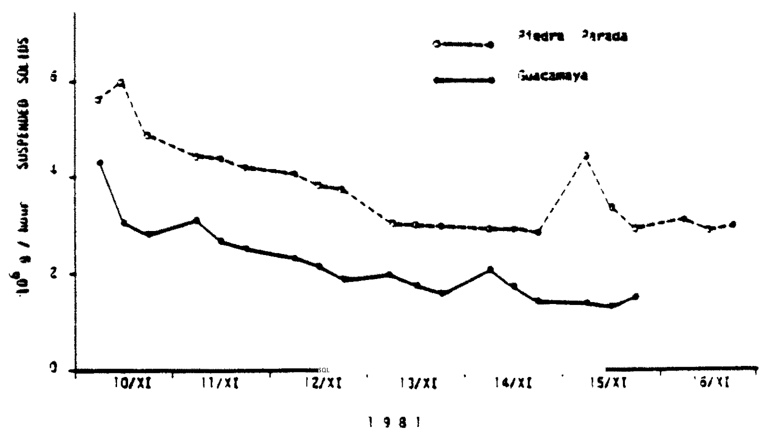

(c)

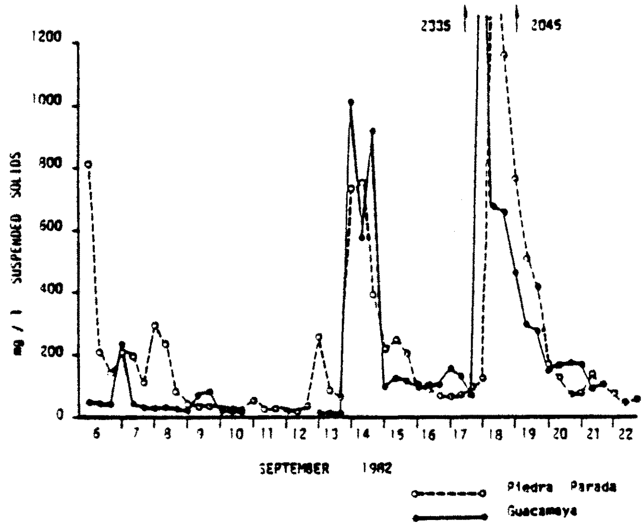

Figure 6.6 (a-c) Concentrations and loading rates of suspended sediment at two stations on the Humuya river, September 1981 and November 1982.

Figura 6.6 (a-c) Concentracions y cantidades acareadas de sedimentes suspendidos en dos estaciones del río Humuya, septiembre 1981 y noviembre 1982.

similar above and below Ojos de Agua. The flow data which exist for September 1982, indicate that a similar difference between the two stations would also be expected for the wet season).

The percentage of suspended sediment which was combustible, i.e. percentage ash free dry weight (%AFDW, roughly equivalent to percentage organic matter) ranged from less than 10% to over 70% at El Cajón. The mean % AFDW ($\pm$ 1 standard deviation) during the dry season (January to April) was 39($\pm$ 24)%, and during the wet season, (June-September) 11($\pm$ 4). Less seasonal difference in the % AFDW was seen in the R. Yure. Dry and wet season means ($\pm$ 1 standard deviation) were 36($\pm$ 24)% and 32($\pm$ 28)%, respectively, at the Yure station, reflecting the uniformly low sediment loads of this river.

The generally higher percentage of organic matter in the rivers during the dry season presumably reflected both increased algal primary production in the slower-flowing, less turbid water, and a reduction in the erosional input of mineral particles. There were few consistent differences in % AFDW between upstream and downstream stations (those which could be compared through being sampled either on the same dates, or in the dry season when temporal variation was reduced). The % AFDW of suspended solids at Ojos de Agua, for example, varied from 0.4 - 2.5 x the values at Comayagua. % AFDW was generally higher in the R. Chiquito, however. This was to be expected from the discharge of sewage into that river.

The % AFDW of suspended material at river stations below the dam site varied little, either between sampling sites or between dates (Tables A2.10-A2.13). Values were generally between 10 and 20% and, except for one occasion at one station, never reached the higher levels frequently exhibited at most of the stations upstream from El Cajón. This could have been an artifact of sampling frequency, but is more likely to have been real (compare, for example, with the stations at Ojos de Agua and Comayagua, which were sampled at a similar frequency). The relatively consistent values of % AFDW at these downstream stations was interesting in view of the fact that a wide variation in suspended solids concentrations was observed during the year of sampling. Most variation in sediment concentration was seen at Santa Rita, just upstream from the confluence with the Ulúa river. The fact that the high suspended solids concentrations at Santa Rita in July and September 1980 were not observed at stations further downstream suggests that either a wave of turbid water resulting from a storm(s) had not yet reached San Manuel or that Humuya water was being diluted by the Ulúa. At the confluence of the Ulúa and Humuya rivers, the average annual discharge of the former river is very similar to that of the latter (calculated from data in Motor Columbus 1977). Thus there is at least the potential for a significant dilution of turbid Humuya water by the Uhúa.

6.2.7 Phosphorus

Phosphorus is extremely important to the fertility of terrestrial and aquatic environments. It occurs in fresh waters in a variety of forms, ranging from dissolved orthophosphate ($PO_4^{\equiv}$), through higher molecular weight, dissolved compounds (e.g. phosphomonesters and polyphosphates), to particulate phosphorus. Particulate phosphorus in rivers is usually composed of material eroded from bedrock and soil, but in lakes and in slower flowing, clear rivers, a large proportion is represented by the phosphorus incorporated into cells (for example, phytoplankton).

Various forms of phosphorus can be separated by different analysis pre-treatments. In the present study two forms of phosphorus were assayed, soluble reactive phosphorus (SRP) and total phosphorus (TP). SRP represents the dissolved phosphorus fraction (i.e. that which passes through a 0.45 µm filter) which reacts directly with acid molybdate (see method, Appendix 9). SRP is mainly orthophosphate ($PO_4^{\equiv}$), but also may include some higher molecular weight forms of phosphorus (Goldman and Horne 1983, Wetzel 1983). In this report, SRP will be termed $PO_4^{\equiv}$-P, for purposes of clarity. There is, however, no assumption that other forms of phosphorus were not present. TP represents all forms which, after acid hydrolysis, react with acid molybdate. TP therefore includes not only particulate phosphorus and $PO_4^{\equiv}$-P (SRP) but also a further form of dissolved phosphorus, soluble unreactive phosphorus (SUP). Although dissolved, SUP only reacts with acid molybdate after acid hydrolysis. SRP was not estimated separately in the present study.

6.2.7.1 <u>$PO_4^{\equiv}$-P concentrations</u>: There were considerable seasonal variations at nearly all stations in the concentration of TP and in the ratio $PO_4^{\equiv}$-P:TP. The greater seasonal variation in TP, relative to $PO_4^{\equiv}$-P, reflects the different processes responsible for transporting particulate and dissolved phosphorus to a river (Leonard et al. 1979). A proportion of the dissolved phosphorus entering a river is associated with water that has passed through the soils of the watershed, i.e. subsurface and groundwater flow. The dissolved phosphorus content is thus influenced, often strongly, by the terrestrial ecosystem. Particulate phosphorus, however, is primarily represented by phosphorus contained in or adsorbed to mineral/soil particles. It therefore enters a river via surface runoff and concentrations are often strongly correlated with storm-induced erosional activity.

The seasonal trend in total phosphorus concentrations is best seen at the dam site station (Fig. 6.2b). Dry season concentrations were often between 10 and 20 µg/l*. In May/June, at the beginning of the wet season, there were sharp peaks in TP in each of the 3 years of the monitoring program. These peaks were followed by lower concentrations in June/July and then by higher levels, which

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*Note that nutrient concentrations refer to the element itself. Thus 10 µg/l $PO_4^{\equiv}$-P means that concentration of phosphorus as phosphate and not 10 µg/l ($PO_4^{\equiv}$).

fluctuated greatly, through the remaining part of the wet season. The highest concentration of TP measured at El Cajón was 515 µg/l.

Seasonal variation in $PO_4^{\equiv}$-P at El Cajón was similar to that for TP. The peak concentrations of $PO_4^{\equiv}$-P at the beginning of the wet season, however, were followed by levels which fluctuated about a decreasing or nearly constant mean. Thus, unlike the trend in TP, concentrations of $PO_4^{\equiv}$-P did not rise appreciably between mid-and late-wet season. This is reflected in the percentage of TP represented by $PO_4^{\equiv}$-P (Table 6.1).

The early wet season peak in $PO_4^{\equiv}$-P was largely responsible for the fact that TP concentrations were generally higher at the beginning than at the end of the wet season. The seasonal pattern in $PO_4^{\equiv}$-P concentrations at El Cajón presumably was the result of several interacting factors. During the dry season, plant die-off and burning gradually build up a store of phosphate (and particulate phosphorus) in the upper soil layers. Rains at the beginning of the wet season flush some of this soluble phosphorus into the rivers <u>via</u> surface or subsurface runoff. Some phosphorus also enters the system directly with precipitation (e.g. see Fig. 6.9). As the wet season progresses, and shrubs and annual grasses resume active growth, phosphate becomes increasingly tied up in plant biomass. Adsorption of phosphate to soil particles represents an important additional process whereby phosphorus is removed from subsurface and groundwater flows (Ryden et al. 1973), although adsorptive capacity may subsequently decrease again if water-saturated soils become anaerobic through microbial activity (Patrick and Khalid 1974). In addition, saturation of soils later on in the wet season may lead to an increased tendency for there to be more lateral movement of water on, or close to, the soil surface, reducing the amount of infiltration and thus decreasing the potential for phosphate-uptake (c.f. Leonard et al. 1979). Particulate phosphorus concentrations, on the other hand, are primarily dependent on storm-induced erosional activity in the

Table 6.1: $PO_4^{\equiv}$-P as percentage of total-P, R. Humuya at El Cajón, 1981.

Tabla 6.1: $PO_4^{\equiv}$-P como porcentaje de P-total, R. Humuya, El Cajón, 1981.

Month	Mean%	Range%
1	78	--
11	49	36-73
111	60	23-90
1V	42	25-57
V	30	18-38
V1	23	11-38
V11	22	11-34
V111	12	4-18
IX	13	0
X	27	11-43
XI	41	21-73
XII	62	35-100

watershed and thus are correlated with the suspended sediment load of the rivers.

Higher wet season concentrations of phosphorus were seen at other stations on the Humuya and Sulaco rivers, although within-season trends were not as clear as at those stations sampled weekly or biweekly. In the R. Chiquito, phosphorus concentrations peaked at the beginning of March and then fluctuated around a decreasing mean through the end of the wet season. $PO_4^{\equiv}$-P usually represented over 60% of the total phosphorus concentration of the R. Chiquito. Maintenance of a high percentage of $PO_4^{\equiv}$-P throughout the wet season in this river probably from a relatively low variation in stream flow, reduced input of suspended matter and the discharge of municipal waste-water. It should be noted that on the two occasions when high concentrations of suspended solids were measured (December 1979, October 1980), phosphorus concentrations were relatively low (Table A2.3). Conversely, the peak phosphorus concentrations were measured on a sample which exhibited a fairly low sediment content. The reasons(s) for the sharp increase in phosphorus concentrations between February and March (1980) is not known.

The impact on the R. Humuya of the relatively high $PO_4^{\equiv}$-P levels of the R. Chiquito appeared to be minimal. Concentrations at Ojos de Agua were generally lower than those at Comayagua. This appears to have been because when the flows of both rivers were of similar magnitude (December 1979 - February 1980, Tables A2.2 and A2.3), phosphate concentrations were similar. However, when the R. Chiquito exhibited much higher phosphate levels than the R. Humuya, its flow was considerably reduced relative to that of the Humuya. (Flows greater than about 5 m^3/s, however, could not be measured, so it was not possible to calculate dilution ratios throughout the wet season).

$PO_4^{\equiv}$-P concentrations of Sulaco water were generally lower than those of Humuya water, although similar seasonal trends were seen in both rivers. The mean $PO_4^{\equiv}$-P concentration for 1980 at Victoria, for example, was 19($\pm$21) μg/l. For the R. Humuya at Comayagua, the mean was 50($\pm$22) μg/l. Although $PO_4^{\equiv}$-P concentrations at Humuya stations downstream from Comayagua were generally lower than the concentrations at Comayagua itself , a difference in the baseline (dry season) phosphate levels of the Humuaya and Sulaco rivers was still evident at the confluence of these two rivers (Fig. 6.2b). Furthermore, a comparison of Humuya $PO_4^{\equiv}$-P concentrations above and below the Sulaco confluence (Fig. 6.2b) shows that Sulaco water was usually diluting Humuya water in both wet and dry seasons, thus again indicating generally lower $PO_4^{\equiv}$-P concentrations for the R. Sulaco. (See plate 6.F).

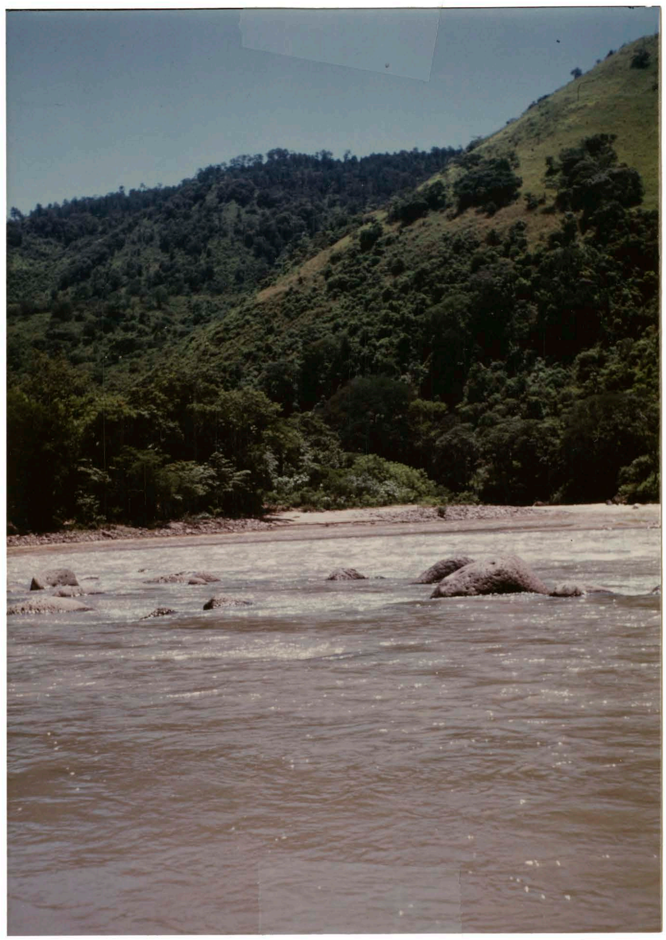


Plate 6.F. Confluence of Rio Sulaco and Rio Humuya.
Rio Sulaco is in the background.

Foto 6.F. Confluencia del Rio Sulaco y Rio Humuya.
El Rio Sulaco esta arriba.

It is difficult to make similar comparisons between the TP concentrations of the Humuaya and Sulaco rivers, because of the large short-term fluctuations in this parameter. However, there were no obvious, consistent differences between the two rivers, except for a small dilution effect by Sulaco water on dry season Humuya TP concentrations. This effect however is the same as that discussed above, since dry season TP was primarily $PO_4^{\equiv}$-P.

In contrast to the pronounced seasonal and shorter-term fluctuations in the TP concentrations of the Humuya and Sulaco rivers, variation in TP levels at both upstream and downstream stations on the R. Yure was relatively low (Fig. 6.2b). This reflected major differences between the R. Yure and the R. Humuya and Sulaco in terms of size, drainage area (Table 7.1) and erosional input of suspended sediment. Seasonal trends in Yure TP concentrations were dominated by trends in $PO_4^{\equiv}$-P, since phosphate comprised 30-80% of TP in the wet season and more than 80% in the dry season. In contrast to the low TP concentrations of the R. Yure, the range of $PO_4^{\equiv}$-P concentrations was similar to that observed in the Humuya and Sulaco rivers. The pattern of seasonal variation, however, was rather different. At the Yure station, $PO_4^{\equiv}$-P concentrations increased through the dry season reaching a peak at, or before, the onset of the rains, and then gradually decreased through the wet season, remaining at low levels from August to December. This gradual dry season increase in $PO_4^{\equiv}$-P was not seen in the larger rivers, and presumably reflected an increasing concentration of groundwater runoff as the dry season progressed, and/or a decreased inflow of relatively dilute surface or subsurface runoff.

Seasonal variation in $PO_4^{\equiv}$-P at the downstream station on the R. Yure (Fig. 6.2d; note change of scale) was the least of any of the stations monitored for this study (with the exception of the tributaries to L. Yure). Concentrations did increase slightly through the dry season, but then remained relatively constant until August when they decreased by about 80% through December.

At stations on the R. Humuya/Ulúa downstream from El Cajón, the trend towards higher wet season concentrations of TP was most evident at Santa Rita. The more uniform TP concentrations at the other three stations may have been an artifact of the monthly sampling frequency (floods being "missed" at these three stations; compare, however, with graphs of suspended solids concentrations, Fig. 6.3), and/or have represented a damping effect of the Ulúa river.

$PO_4^{\equiv}$-P usually represented between 10 and 65% of TP at all four downstream stations, with values being higher in the dry season than in the wet season (Table 6.2).

Table 6.2: $PO_4^{\equiv}$-P as percentage of total-P at four stations on the R. Humuya/Ulúa, downstream from El Cajón.

Tabla 6.2: $PO_4^{\equiv}$-P como porcentaje de P-total en cuatro estaciones en el R. Humuya/Ulúa, río abajo de El Cajón.

Date	Santa Rita	San Manuel	El Progreso	Guanacastales
12/12/79	44	36	64	49
16/1/80	67	54	57	53
13/2/80	100	32	38	47
12/3/80	67	45	59	50
23/4/80	46	55	70	23
14/5/80	33	40	43	47
11/6/80	33	34	32	27
9/7/80	16	22	21	22
13/8/80	26	21	23	22

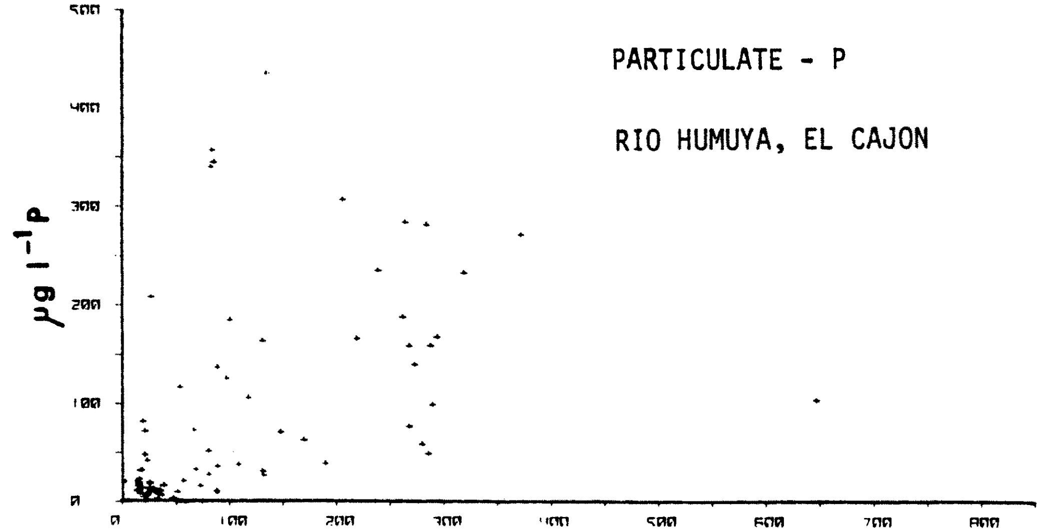
Seasonal fluctuations in $PO_4^{\equiv}$-P concentrations differed between the four downstream stations. The reason for these differences is not obvious, but may have been partly related to phosphorus inputs from city waste-water or from fertilized agricultural land. (Note that the trend in $PO_4^{\equiv}$-P for the R. Ulúa at El Progreso (Fig. 6.3) was similar to that for the R. Chiquito at Comayagua [Fig. 6.2d]). There was an increase in $PO_4^{\equiv}$-P base-level concentrations between Santa Rita and Guanacastales. Between December and February, for example, the mean concentration of $PO_4^{\equiv}$-P was 17, 25, 41, and 41 µg/l at Santa Rita, San Manuel, El Progreso and Guanacastales respectively. This increase was probably a result of the inflow of the R. Ulúa below Santa Rita and of agricultural and urban drainage.

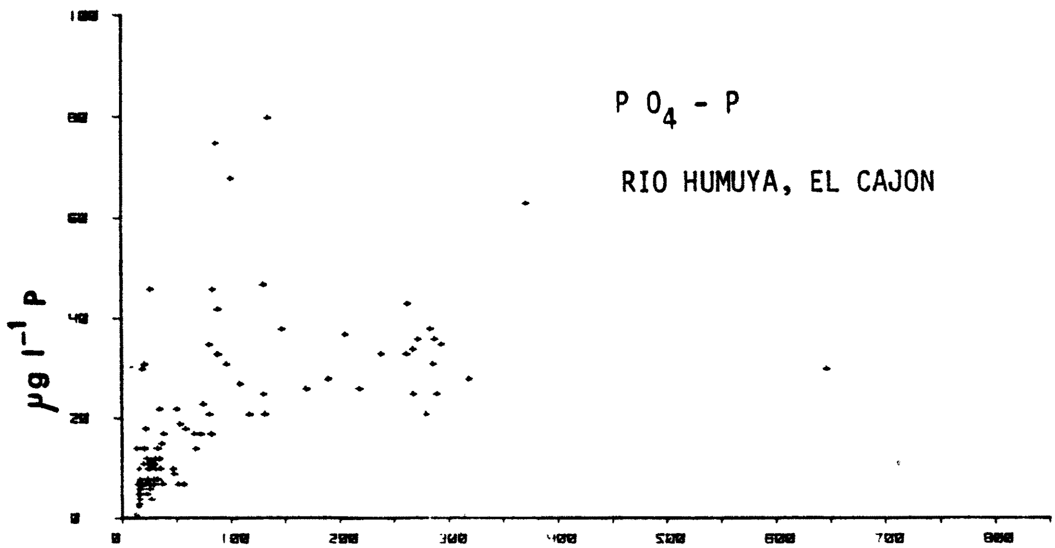
6.2.7.2 <u>Phosphorus Concentrations vs. River Discharge</u>: The differences between the R. Yure and the larger rivers with respect to seasonal trends in phosphorus concentrations are further reflected in the graphs of concentration versus river discharge (Fig. 6.7). For the R. Humuya, increasing discharge was associated with higher phosphorus concentrations, although there was a high variance with particulate phosphorus (Note: particulate phosphorus concentrations were calculated by subtracting $PO_4^{\equiv}$-P from TP; thus they really represent particulate phosphorus and soluble unreactive phosphorus). Phosphate concentrations increased to about 30 µg/l and then remained relatively constant at discharges greater than about 150 m^3/s. In the R. Yure, however, there was an inverse correlation between discharge and concentration, reflecting a dilution of river water during periods of higher flow.

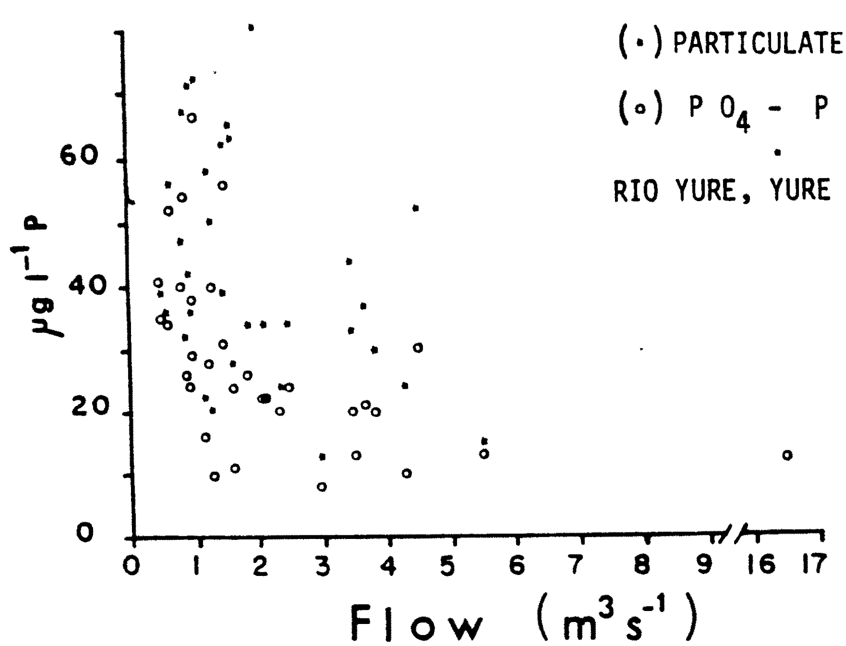
6.2.7.3 <u>Loading rates:</u> Loading rates were calculated by multiplying concentration with discharge and are presented in Figs. 6.8 and 7.16. Increased loading rates in the wet season resulted primarily from the higher river discharge at that time. However, the positive correlation betweeen phosphorus concentration and discharge for the R. Humuya and the negative correlation for

Figure 6.7: Relationship between phosphorus concentration and river discharge rate for the R. Humuya at El Cajón and the R. Yure at Yure.

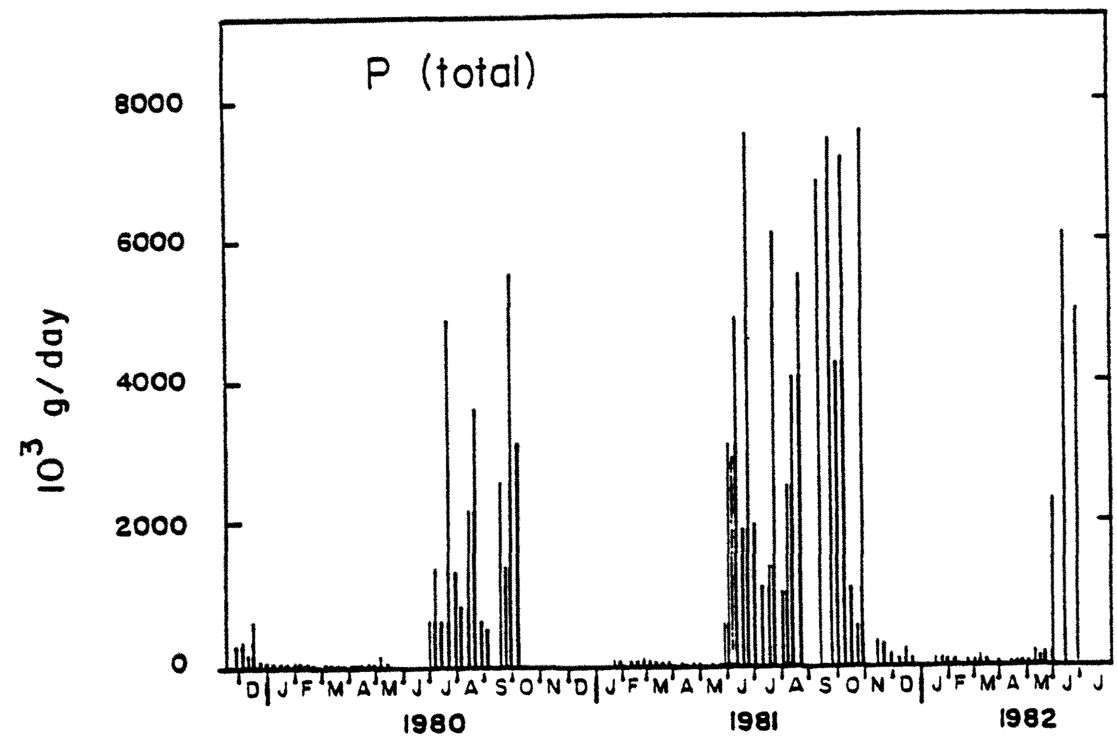
Figura 6.7: Relación entre la concentración de fósforo y la descarga del río para el R. Humuya en El Cajón y el R. Yure en Yure.


PARTICULATE - P
RIO HUMUYA, EL CAJON
μg l⁻¹ P


P O4 - P
RIO HUMUYA, EL CAJON
μg l⁻¹ P


(•) PARTICULATE - P
(∘) P O4 - P
RIO YURE, YURE
μg l⁻¹ P
0
20
40
60
0 1 2 3 4 5 6 7 8 9 16 17
Flow (m³s⁻¹)

(a)



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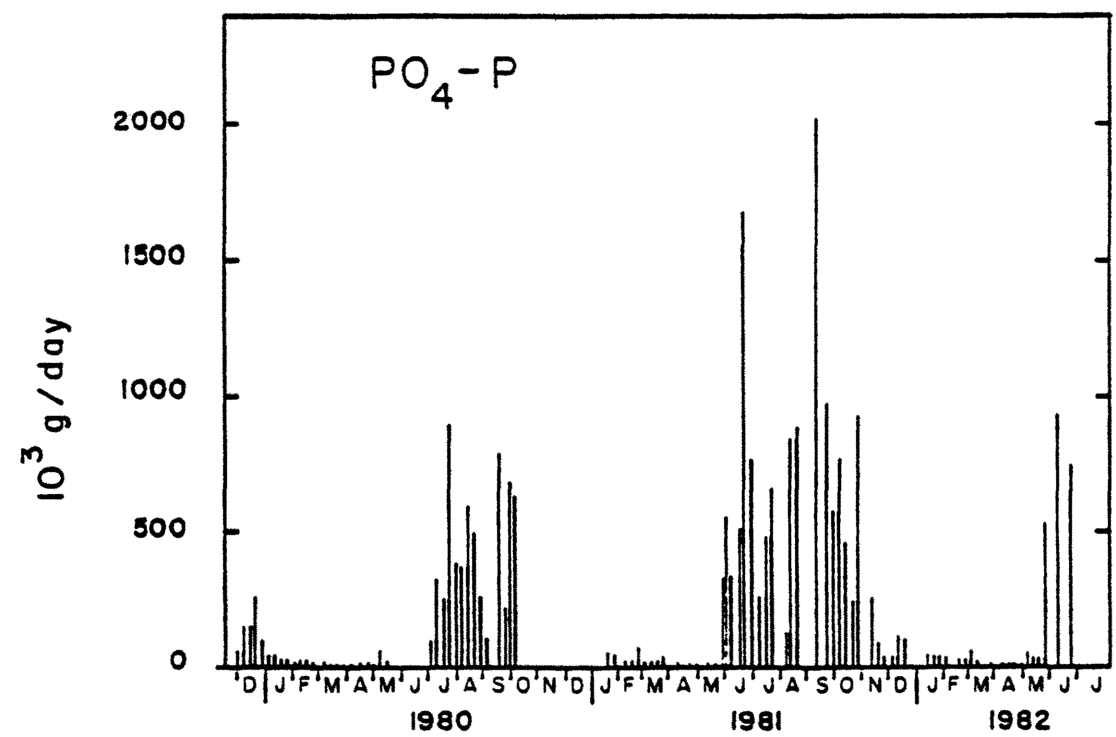


Figure 6.8: Phosphorus loading rates for the R. Humuya at El Cajón.

Figure 6.8: Cantidades de fósforo acareadas por el R. Humuya en El Cajón.

the R. Yure served to respectively increase and decrease the difference between wet and dry season loading rates in these two rivers.

6.2.8 Nitrogen

Nitrogen, like phosphorus, is an important nutrient in establishing the fertility of aquatic ecosystems. The major natural sources of nitrogen are precipitation, biological fixation and decomposing organic matter. This is in contrast to phosphorus where the primary source is usually naturally occurring minerals. The concentration of inorganic nitrogen (as nitrate and ammonia) in soil- and river-water is dependent on several factors, including: a) the nitrogen content of precipitation (both wet and dry), b) the presence and activity of nitrogen-fixing species, both plant and microbial, c) the loss of nitrogen by denitrification (whereby NO_3-N is reduced to N_2), d) the adsorption of NH_4-N by soil particles, e) nitrification (the oxidation of ammonia to nitrate), f) the uptake by plants of NO_3-N and NH_4-N, and g) watershed slope and soil structure which influence the relative contribution of surface, sub-surface and groundwater runoff, (e.g. Leonard et al. 1979, Lewis 1981, Triska et al. 1984, Whitton 1975, Likens et al. 1977).

Dissolved organic nitrogen is often a significant component of total soluble nitrogen in freshwaters (e.g. Wetzel 1983, Leonard et al. 1979). This fraction was not measured in the present study, however.

6.2.8.1 NO_3-N concentrations: Average wet season NO_3-N concentrations were higher than average dry season concentrations at all river stations sampled in the monitoring program (Fig. 6.1). However, seasonal fluctuations in NO_3-N were not always as well defined as they were for phosphorus. At El Cajón , NO_3-N concentrations were generally highest at the beginning of the wet season or in October/November (Fig. 6.2a). Between July and September concentrations were approximately one half of the peak values. In the dry season, NO_3-N concentrations were often very low (<10 µg/l), especially in December and March/April. However, they often increased between January and March. This was most clearly seen at El Cajón in 1982, but was also apparent in other years at this station and at other stations, e.g. R. Humuya at Sulaco confluence.

Burning releases much of the nitrogen contained in vegetation to the atmosphere in the form of nitrogen oxides, which are then flushed out during rainstorms (Lewis 1981). This would account for the high NO_3-N concentrations observed at the beginning of the wet season, and possibly also for the dry season peaks since some precipitation occurs at that time of year. Precipitation chemistry was not routinely monitored during the present study but Fig. 6.9, taken from Kellman et al. 1982, illustrates seasonal variation in the input of soluble elements via precipitation, at Siguatepeque during 1978 and 1979.

Concentrations of NO_3-N in the R. Humuya at the Sulaco confluence were similar to those at El Cajón indicating that Sulaco and Humuya concentrations differed little from each other (unlike the situation for $PO_4^{\equiv}$-P). NO_3-N levels were also similar at the upstream stations on the Humuya and Sulaco rivers (Comayagua and Victoria, respectively), but distinct early and late wet season peaks were more apparent at Victoria (Fig. 6.2c).

Average dry and wet season NO_3-N concentrations of the R. Chiquito were higher than those of all the other stations sampled in the monitoring program, with the exception of the tributaries to L. Yure (Figs. 6.2c and 6.4). The R. Chiquito at times had a apparently significant influence on the NO_3-N concentration of the R. Humuya, for example in September and November 1980 when R. Chiquito NO_3-N levels were high (Fig. 6.2c; note, however, that concentrations on these dates were even higher downstream at the Yure confluence).

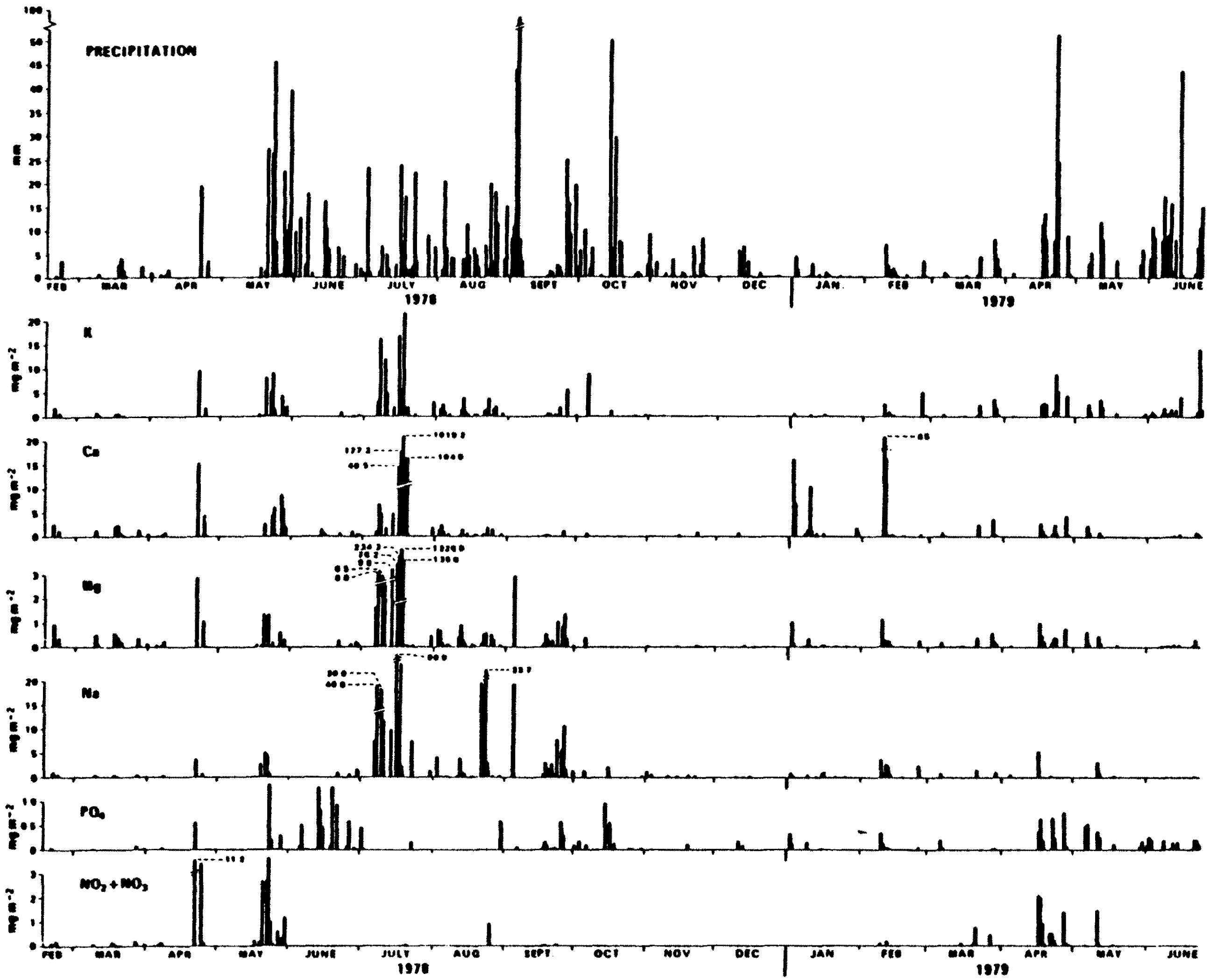


Figure 6.9: Daily precipitation and input of soluble elements at Siguatepeque over a 16-month period. Trace inputs are recorded as zero. (From Kellman et al 1982).

Figura 6.9; Precipitación diaria y la introducción de elementos solubles en Siguatepeque durante un período de 16 meses. Cantidades trazas son tomadas como cero. (Tomado de Kellman et al 1982).

NO_3-N concentrations of the R. Yure at Yure and at the Humuya confluence were similar to those of the Humuya and Sulaco rivers and exhibited similar seasonal trends. During part of the wet season, however, (July - September) there was an apparent decrease in NO_3-N between the stations at Yure and the Humuya confluence.

The former headwaters of the R. Yure, now the tributaries to L. Yure, exhibited higher NO_3-N levels than any of the other stations on the Yure, Humuya and Sulaco rivers (Fig. 6.4). For example, mean concentrations ($\pm$ 1 standard deviation) in 1980 and 1981 for Q. del Cerro were 187 ($\pm$90) and 165 ($\pm$81) μg/l, respectively. Those for the R. Yure at Yure were 56 ($\pm$37) and 39 ($\pm$28) μg/l, and for the R. Humuya at the Sulaco confluence, 56 ($\pm$ 47) and 40 ($\pm$31) μg/l. NO_3-N levels in the L. Yure tributaries were thus similar to those of the R. Chiquito, but much higher than those of the small stream Q. El Cajón (Table A2.9). The pattern of seasonal variation in NO_3-N was different in each of the three years of the study, although there was a general trend towards higher concentrations between June and November. In 1981 highest concentrations were observed at the end of the year.

There was a trend towards a decrease in annual mean NO_3-N concentrations with increasing size (discharge) of the L. Yure tributaries. Mean concentrations were 165, 121 and 83 μg/l for Q. Sin Nombre, Q. del Cerro and Q. Tepemechín, respectively. Differences, however, were not statistically significant, because of the high associated variances. The relatively high NO_3-N levels of the L. Yure tributaries are interesting, both in relation to concentrations typical of the other rivers and in terms of the nutrients potentially limiting phytoplankton growth in L. Yure. In some Californian streams, NO_3-N concentrations are lower in the headwater reaches than at stations further downstream (Triska et al. 1983). Although the opposite trend was apparently observed with the R. Yure, it is impossible, with the existing data base. to know if the difference in concentrations between headwater and downstream sections of the R. Yure resulted from processes occurring within the stream channel (e.g. denitrification, Triska et al. 1984), or simply the diversion by the Yure dam of the nitrate-rich headwaters. It is probable however, that NO_3-N concentrations of at least the mid-section of the R. Yure were higher before the Yure dam was constructed, since the total discharge of the L. Yure tributaries would have represented a significant contribution to the flow of the R. Yure at Yure (Tables A2.15-18).

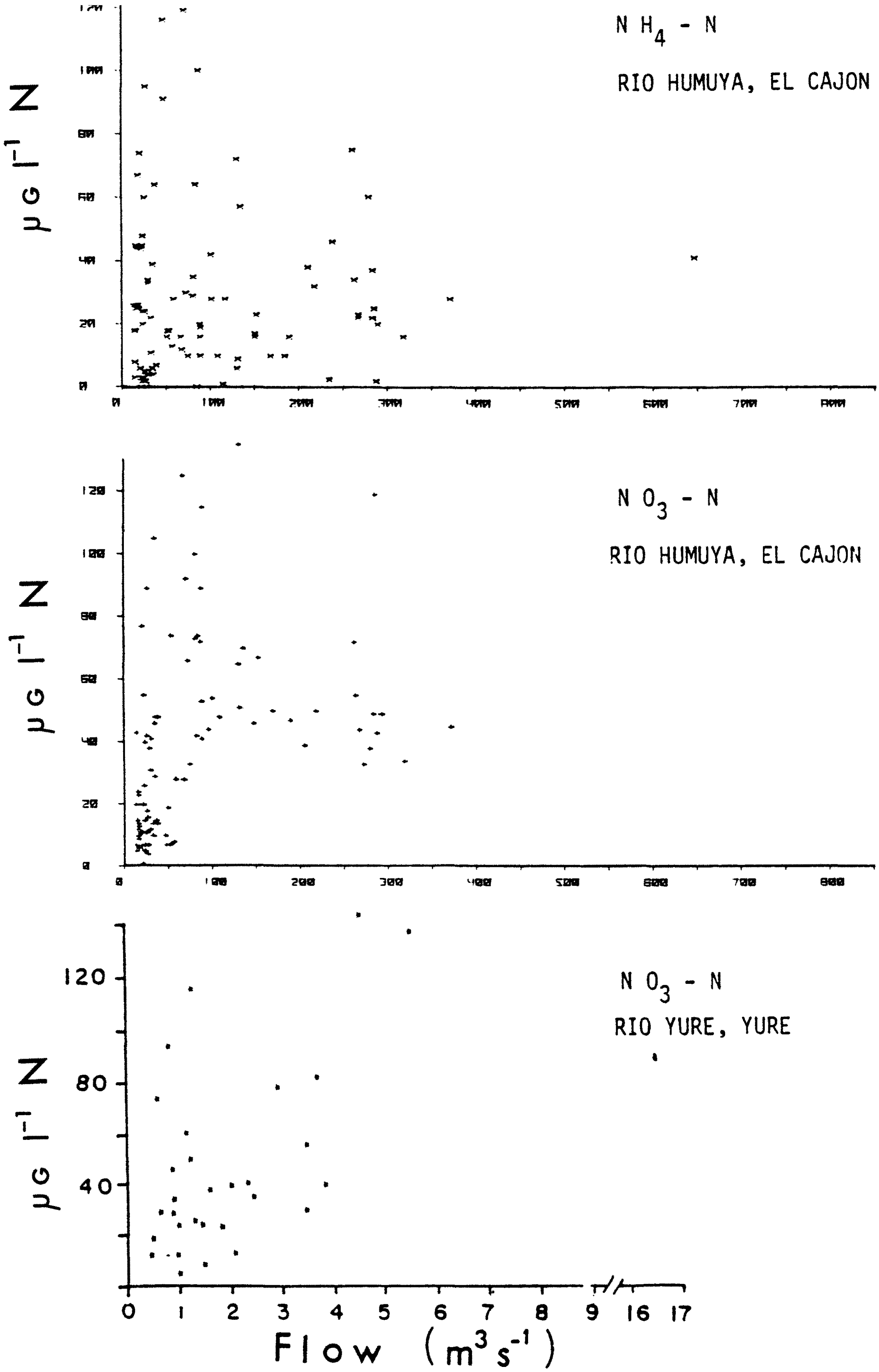
At all four stations on the R. Humuya and Ulúa downstream from El Cajón, NO_3-N concentrations were usually similar on any particular sampling date. Seasonal variation was comparable to that described above for other stations, with a trend towards higher concentrations from June to November. There were no obvious or consistent differences between the Santa Rita and San Manuel stations, indicating that the inflowing R. Ulúa did not differ significantly from the R. Humuya in terms of NO_3-N.

6.2.8.2 <u>NO_3-N Concentrations vs. River Discharge</u>: The relationship between concentration of NO_3-N and river discharge rate is illustrated in Fig. 6.10 for the R. Humuya at El Cajón and R. Yure at Yure. At El Cajón , the variation in NO_3-N with discharge was similar to that for PO_4-P, although there was much greater variation in NO_3-N concentrations at low river flows. This may reflect the influence on river NO_3-N levels of infrequent precipitation events in the dry season coupled with burning activity in the watershed.

There was no clear relationship between NO_3-N concentration and discharge for the R. Yure at Yure although there was some indication of a weak positive correlation. The poor correlation between these two parameters was probably in part a result of the restricted range of river discharge rates observed during

Figure 6.10: Relationship between inorganic nitrogen concentration and river discharge rate for the R. Humuya at El Cajon and the R Yure at Yure.

Figura 6.10: Relación entre la concentración de nitrógeno inorgánico y la descarga del río para el R. Humuya en El Cajón y el R. Yure en Yure.



μG l⁻¹ N
N H4 - N
RIO HUMUYA, EL CAJON
μG l⁻¹ N
N O3 - N
RIO HUMUYA, EL CAJON
μG l⁻¹ N
120
80
40
N O3 - N
RIO YURE, YURE
0 1 2 3 4 5 6 7 8 9 16 17
Flow (m³s⁻¹)

the study. However, the influence of increasing discharge on R. Yure NO_3-N concentrations was quite different from the dilution effect observed for PO_4-P (Fig. 6.7).

6.2.8.3 NH_4-N concentrations: Ammonia is a product of the microbial decomposition of organic matter and is also a major excretory product of aquatic animals. The concentration of NH_4-N in unpolluted fresh waters is usually very low because of its rapid uptake by both aquatic and terrestrial plants. Furthermore, ammonia is strongly adsorbed by soil particles and thus tends to be retained within the terrestrial ecosystem.

Average concentrations of NH_4-N were similar in dry and wet seasons at most of the stations monitored during this study (Fig. 6.1). Concentrations were often low relative to NO_3-N (<20%); however there was much variation and the ratio NH_4-N:NO_3-N at times exceeded unity (Tables A2.1-19). NH_4-N levels were much higher in the R. Chiquito than at any of the other sampling stations, this presumably resulting from the discharge of waste-water from the city of Comayagua. However, these high concentrations apparently had no significant influence on the NH_4-N levels of the R. Humuya since concentrations were similar at Comayagua and Ojos de Agua.

Seasonal variation in NH_4-N loading rate is illustrated in Figs. 6.11 and 7.16 for the R. Humuya at El Cajón and for the L. Yure tributaries, respectively. River flow was the principal factor influencing this variation.

The NH_4-N concentration data will not be discussed in more detail here, owing to 1) the lack of distinct seasonal patterns and 2) interpretation problems associated with the methodology for ammonia analysis (primarily the extreme ease with which samples or reagents can be contaminated by atmospheric ammonia sources). Nevertheless, the lack of any distinct seasonality in NH_4-N levels may be a demonstration of the degree to which terrestrial ecosystems

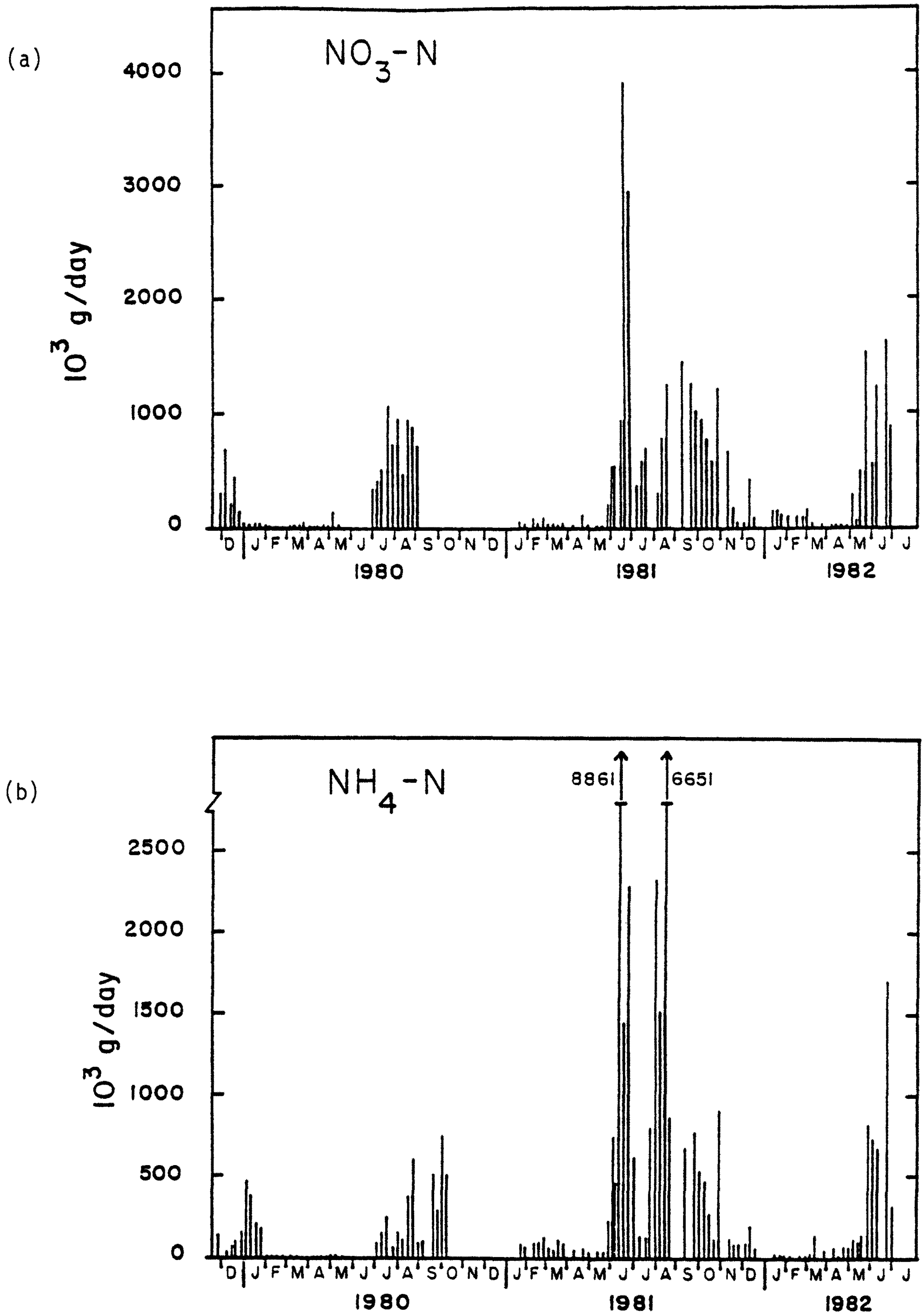


Figure 6.11: Inorganic nitrogen loading rates for the R. Humuya at El Cajón.

Figura 6.11: Cantidades de nitrógeno inorgánico acareadas por el R. Humuya en El Cajón.

strongly retain this form of inorganic nitrogen, either by incorporation into plant biomass or by adsorption onto soil and mineral particles. Although they were not studied in the present program, inputs of NH_4-N to terrestrial systems (for example via precipitation) often exhibit distinct seasonal fluctuations (e.g. Likens et al. 1977, Lewis 1981, Kellman et al 1982, Fig. 6.9).

6.2.8.4 Nitrogen to Phosphorus Ratios: Primary production in freshwaters is often found to be limited by either nitrogen or phosphorus; that is an increase in either (or both) of these nutrients leads to an increase in productivity. The ratio of nitrogen:phosphorus in plants is approximately 7N:1P by weight (Wetzel 1983). A comparison of this ratio to that for stream or lake water often allows an indication to be obtained of whether N or P may be limiting in the system. If the N:P ratio is greater than about 10:1, phosphorus is probably limiting. When the ratio is less than about 5:1, then the limiting nutrient is often nitrogen. In some systems neither N nor P is limiting; the important factor may be iron or trace elements, for example. However, the N:P ratio represents an initial and easily obtainable indicator of the probable limiting nutrient in an aquatic system. Limiting nutrients will be more fully discussed later, in relation to the bioassay experiments (section 7.6).

No consistent seasonal trends in N:total-P ratios were observed at any of the river stations, so values have been averaged over the entire sampling period. They are presented in Table 6.3. There were clear differences between the L. Yure tributaries and the main rivers, reflecting the relatively high headwater nitrogen concentrations that have been previously discussed. The significance of these ratios will be further discussed in section 7.6. Note that, even though nitrogen levels in the R. Chiquito were high, the mean N:P ratio was low because $PO_4^{\equiv}$-P concentrations were also high.

Table 6.3: Average inorganic-N:total-P ratios for rivers of the El Cajón watershed.

Tabla 6.3: Promedio de nitrógena inorgánico:fósforo total para los ríos de la cuenca de El Cajón.

Station	N:P Mean	N:P Standard Deviation	N:P Range	# of observations
R. Sulaco - Victoria	2.5	2.3	0.3 - 8.6	17
R. Humuya - Comayagua	0.9	0.8	0.2 - 2.6	13
R. Chiquito - Comayagua	4.3	6.8	1.2 - 6.2	13
R. Humuya - Sulaco confl.	1.3	1.0	0.2 - 4.0	38
R. Yure - Yure	2.2	2.1	0.1 - 8.6	26
Q. Sin Nombre	15.2	11.0	1.6 - 45.0	45
Q. del Cerro	12.6	9.4	1.1 - 39.3	44
Q. Tepemechín	8.1	10.5	1.1 - 26.1	45

6.2.9 Iron

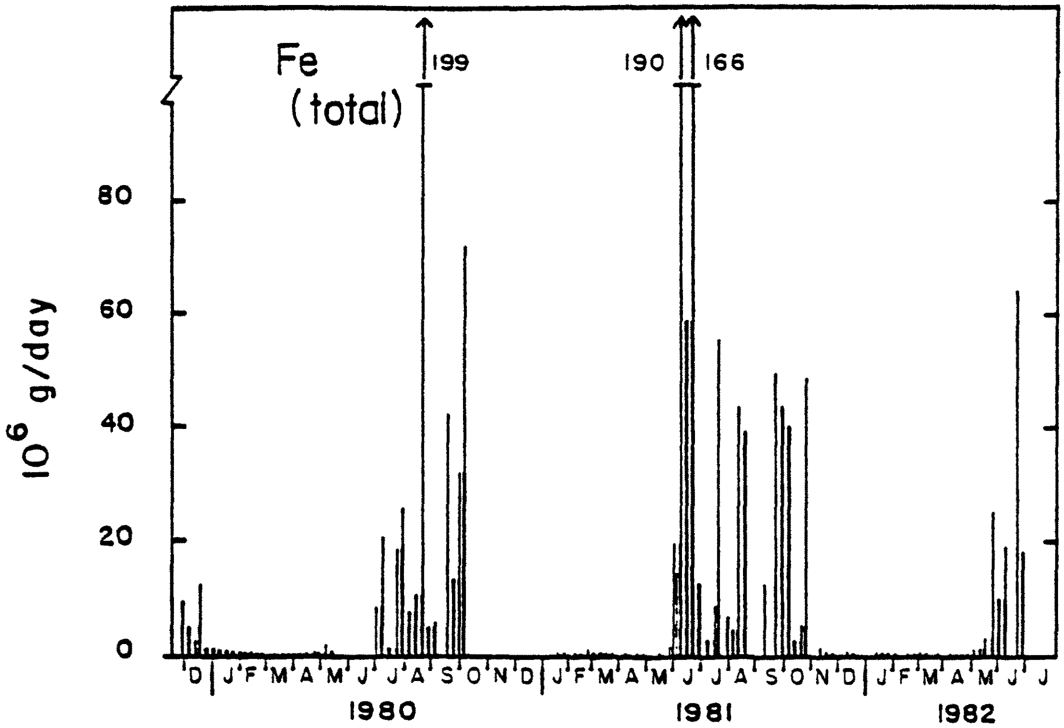
Iron occurs in solution in freshwaters either as the ferrous (Fe^{++}) or ferric (Fe^{+++}) state. Ferrous compounds, however, are generally much more soluble than ferric. The oxidation state of iron plays a fundamental role in the nutrient dynamics of lakes and will be further discussed in section 7, in reference to reservoir water quality and productivity. In the present study, total iron (i.e. particulate and dissolved fractions) was routinely measured. Since the amount of dissolved iron present in well oxygenated waters is usually very low, particulate iron represented the major fraction in all the rivers monitored during the present study. As has been previously discussed (Section 6.2.7), iron-containing particulate matter can influence the concentration of dissolved nutrients (especially $PO_4^{=}$-P) through adsorption, which effectively removes them from solution. The adsorptive capacity of sediments depends on their composition and particle size.

Since iron in rivers is mainly in particulate form, its concentration is usually directly correlated with the concentration of suspended solids. Iron concentrations would therefore be expected to show very distinct seasonal variation. Figs. 6.2 - 6.4 clearly demonstrate that this was the case. Mean wet season iron concentrations were always higher than the usually very low dry season concentrations. Seasonal fluctuation in iron and suspended solids are so similar that no further discussion is necessary here. Referral is made to Section 6.2.6, where these trends are discussed in more detail. (Note that occasional anomalously high iron concentations were documented, i.e. at times when suspended solids concentrations were low, for example Q. Tepemechín on 11/6/81. They probably resulted from contamination by disturbed stream substrate of the samples destined for iron analysis). When iron is expressed in terms of daily loading rates, the variation between seasons is even more extreme than when expressed as concentrations (Fig. 6.12). Fig. 6.13 shows the positive correlation between total iron concentration and river discharge rate for the R. Humuya at El Cajón and the R. Yure at Yure. Variances are high, however.

6.2.10 Silica

The primary source of silica (SiO_2) is the degradation of alumino-silicate minerals (Wetzel 1983). In limnological studies, silica is often of major importance with respect to the population dynamics of diatoms, a group of algae which synthesize hard outer cases, or frustules, from silicon. This will be further discussed in section 7.46. Silica occurs in fresh waters as either dissolved silicic acids or particulate silica. The latter includes silica contained in biotic material (especially diatoms) and that adsorbed to inorganic and organic particles. In rivers, of course, turbulence often maintains in

(a)



(b)

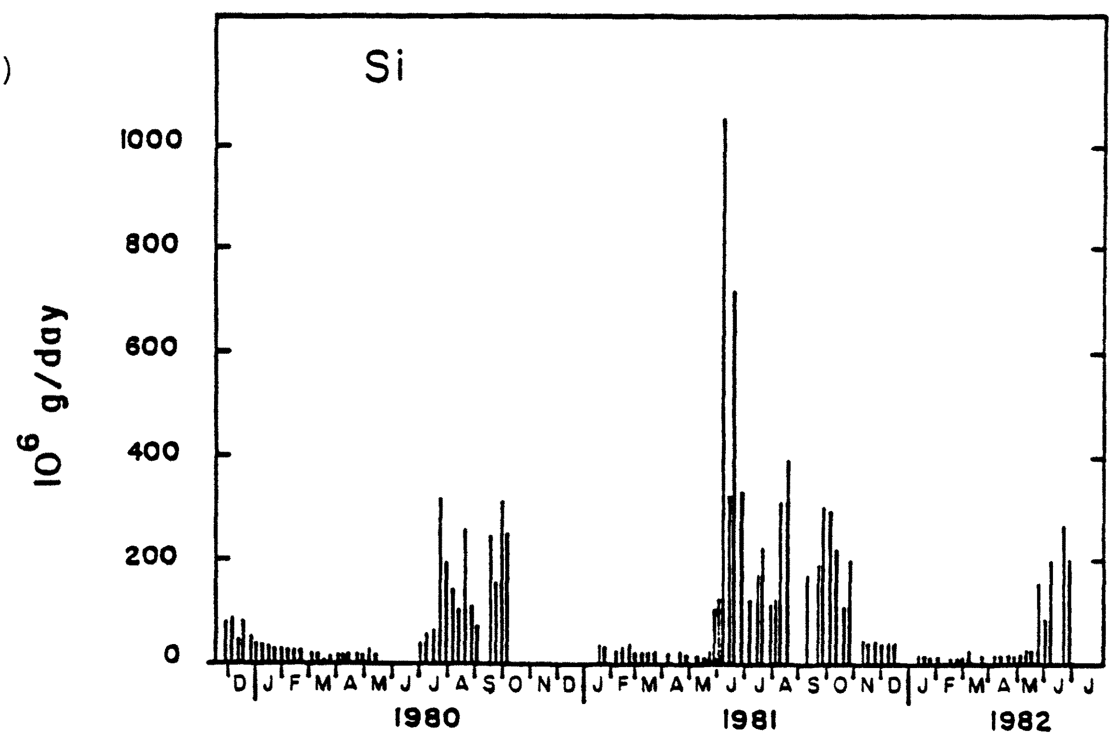


Figure 6.12: Iron and silica loading rates for the R. Humuya at El Cajon.

Figura 6.12: Cantidades de hierro y sílice acareadas por el R. Humuya en El Cajón.

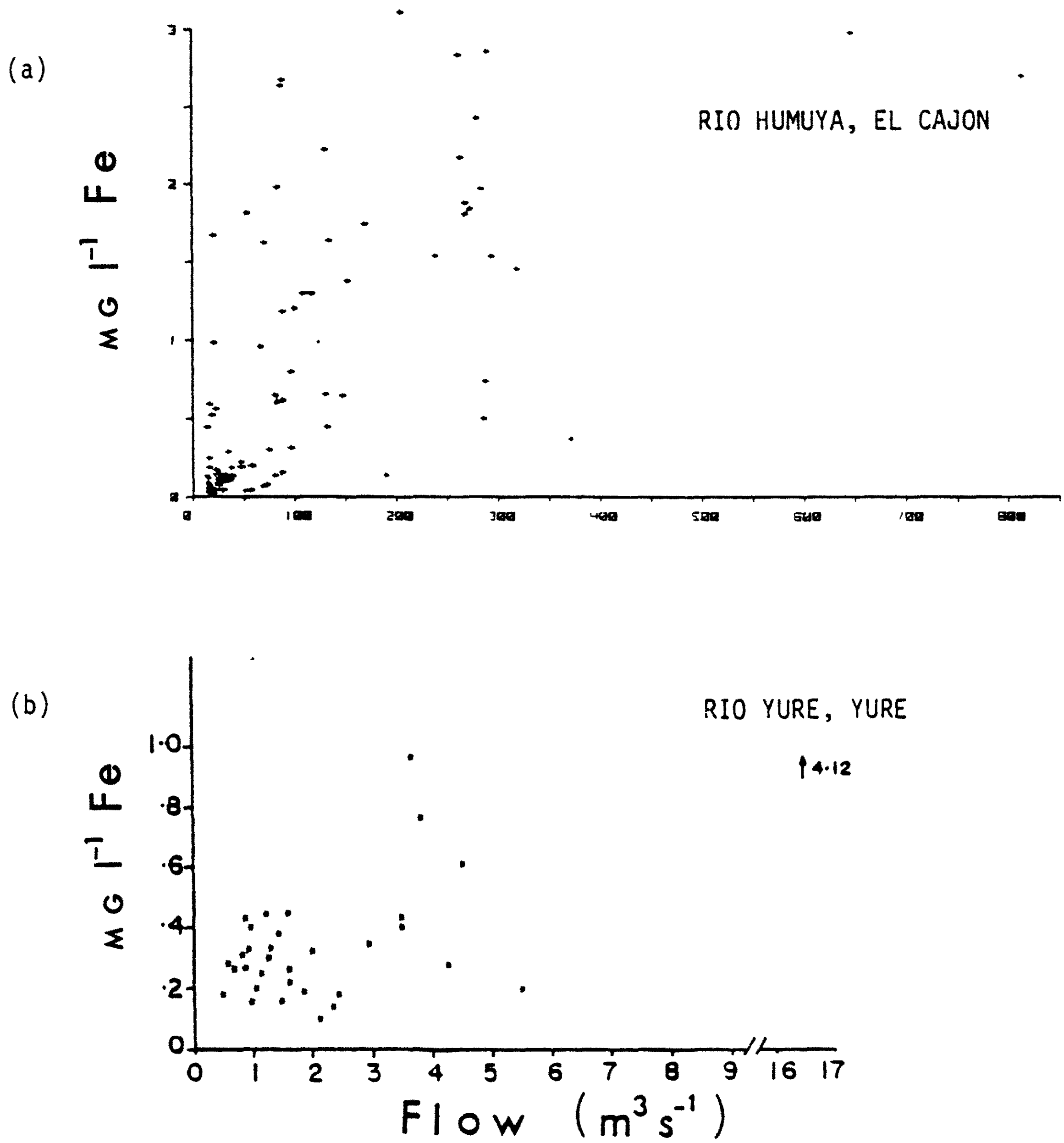


Figure 6. 13: Relationship between total iron concentration and river discharge rate for the R. Humuya at El Cajoń and the R. Yure at Yure.

Figura 6. 13: Relacioń entre la concentracioń de hierro total y la descarga del río para el R. Humuya en El Cajoń y el R. Yure en Yure.

suspension large quantities of sand particles which thus represent a major SiO_2 component. This particulate form, however, is not measured by the molybdate method used in the present study and is not of major interest in limnological work. Thus the SiO_2 levels discussed in this report refer to dissolved, biotic and adsorbed silica, (minus soluble, molybdate-unreactive forms which are of uncertain importance; APHA 1971).

Average wet and dry season SiO_2 concentrations were very similar, with relatively little between-date variation (Fig. 6.1). Mean concentrations were also very uniform between different stations. Seasonal fluctuations in SiO_2 were not marked and the variation that was observed was not consistent. For example, at El Cajón, concentrations apparently increased through the first half of 1980 and then decreased through the second half of the year, whereas in 1981, there was a sharp increase at the beginning of the wet season. For the R. Sulaco at Victoria, little seasonal variation was observed, which contrasted strongly with the higher dry season SiO_2 concentrations for the R. Humuya at Comayagua (Fig. 6.2d). Mean SiO_2 levels at the latter station were also about 50-100% greater than those at all other river stations. The reason for this is not clear. Fig. 6.14 further demonstrates the lack of any distinct seasonal variation in SiO_2 concentrations. There was no relation between concentration and river discharge rates in either the R. Humuya at El Cajón or the R. Yure at Yure. This stability of silica levels has been frequently observed in rivers (Wetzel 1983) and probably results at least in part from a buffering mechanism involving adsorption reactions between solid and dissolved silica phases. In some systems, however, e.g. the Mekong river (Carbonnel and Meybeck 1975), SiO_2 levels have been found to vary inversely with river discharge rates, indicating differences in the concentration of surface and underground waters.

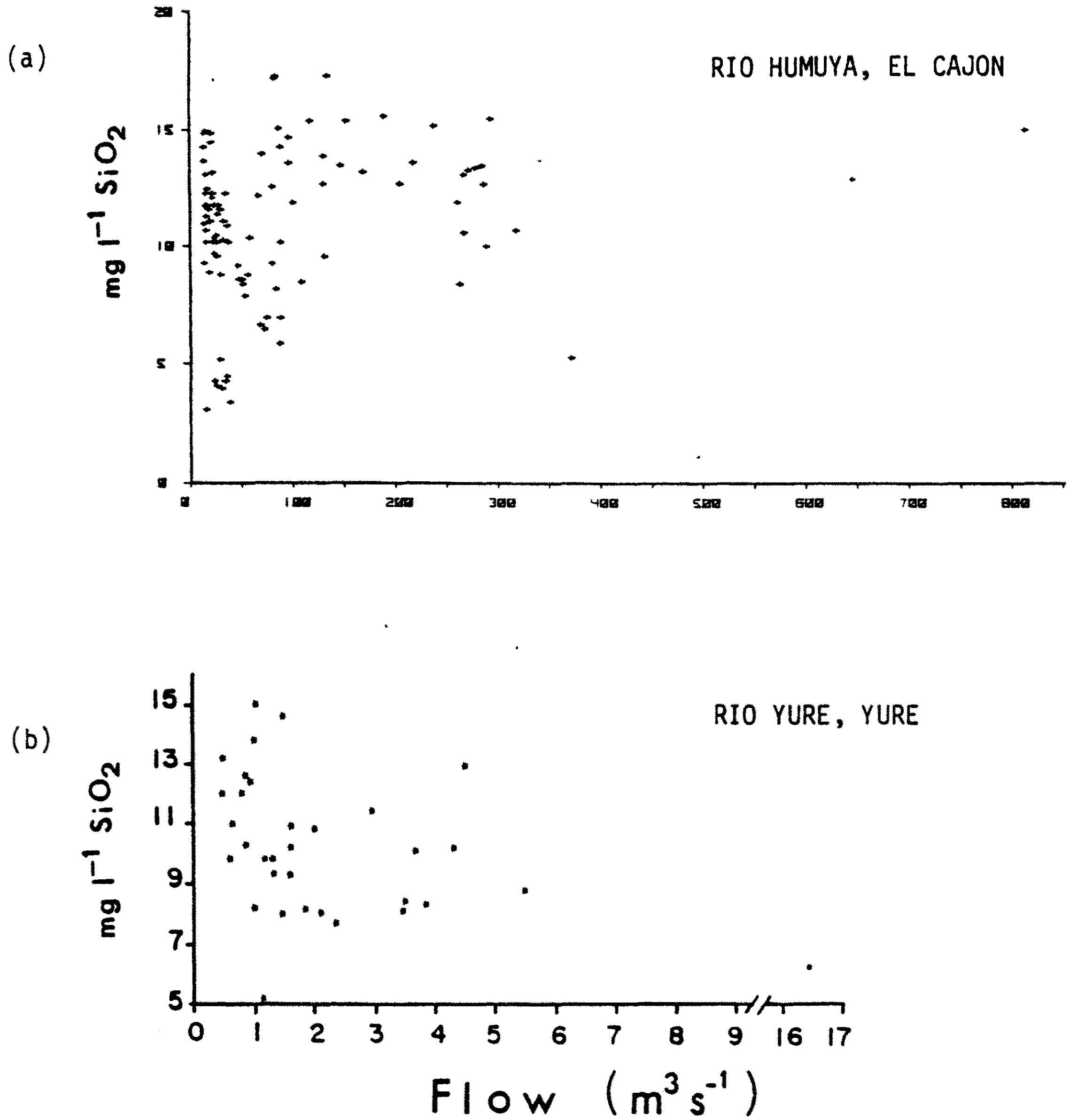


Figure 6.14: Relationship between total silica concentration and river discharge rate for the R. Humuya at El Cajoń and the R. Yure at Yure.

Figura 6.14: Relacioń entre la concentracioń de sílice total y la descarga del río para el R. Humuya en El Cajoń y el R. Yure en Yure.

6.2.11 Sodium, Potassium, Magnesium and Calcium

These four cations are important nutrients for aquatic organisms and there is evidence that the ratio of monovalent to divalent ions ($Na^+ + K^+$: $Mg^{++} + Ca^{++}$) can influence the growth of certain species of algae and thus possibly the phytoplankton community composition of lakes. However, these ions are nearly always present in sufficiently high concentrations (relative to the demand by biota) that they are almost never limiting. They therefore did not constitute a primary area of emphasis in the present study and will not be discussed in detail here.

Mean dry and wet season concentrations of Na^+, K^+ and Mg^{++} were similar at most stations and there was generally little within-season variation (i.e. error bars in Fig. 6.1 are small). At stations where significant seasonal variation in Na^+ concentrations were observed, e.g. R. Humuya at Comayagua and El Cajón, there was usually a dilution effect in the wet season (Figs. 6.1 and 6.15). A similar effect was seen with Mg^{++} concentrations at certain stations, but seasonal differences were less pronounced. Between-season variation was greatest with Ca^{++}, as was also within-season variance. Thus, of the four cations, Ca^{++} was influenced most by changes in river discharge, with higher flow rates usually associated with lower Ca^{++} levels. The one exception was the R. Chiquito where the mean wet season Ca^{++} concentration was higher than that of the dry season. This pattern resulted, however, from the inclusion in the mean value of one sampling date in September when river flow was unusually low and the Ca^{++} concentration unusually high (Table A2.3). This "exception" is therefore consistent with the inverse relationship between concentration and discharge which underlies dry-wet season variation in Ca^{++} levels. The inverse correlation reflects a reduction in the relative importance of groundwater runoff (with its higher Ca^{++} concentrations deriving from dissolution of bedrock and ion exchange) as surface runoff increases in the wet season.

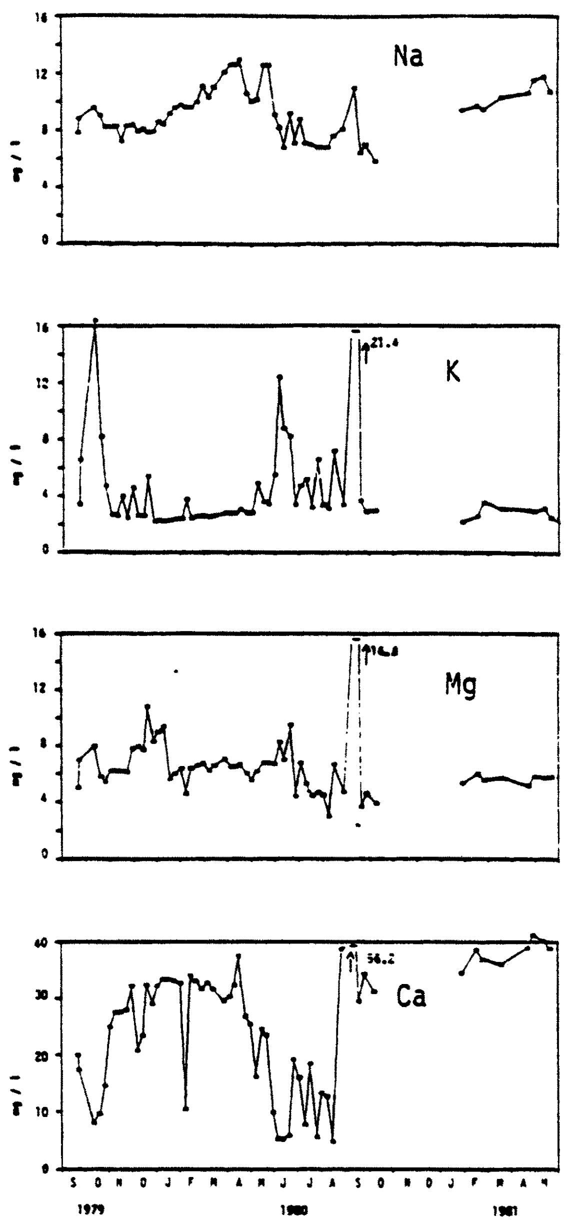


Figure 6.15: Seasonal variation in metal cation concentrations, R. Humuya at El Cajoń.

Figura 6.15: Variacioń estacional en concentraciones de cationes metálicos del R. Humuya en El Cajoń.

The R. Yure exhibited low concentrations of all four cations relative to the R. Humuya. Monovalent cation concentrations were lower in the R. Chiquito and in the R. Sulaco at Victoria than at most stations on the R. Humuya. Divalent cation concentrations were, however, similar at all stations, with the exception of the R. Yure.

6.3 CONCLUSIONS

A number of factors, acting both within the terrestrial ecosystem and within the river channel itself, influence river water quality. These include drainage basin morphology, vegetation cover, bedrock, soil types, meteorology, precipitation chemistry and biotic interactions.

Seasonal variations in a river water quality parameter arise from differences in the value of that parameter between surface and groundwater runoff, in conjunction with the relative contribution of the runoff components to river discharge. In the dry season, most of the water entering a river is from groundwater runoff. This water has infiltrated the various soil layers and its chemistry has been modified by a number of processes, both abiotic and biotic, which represent a chemical "seiving" effect (Ryden et al. 1973). Phosphorus, for example, is often strongly adsorbed to soil particles and thus removed from the infiltrating water, with the result that groundwater runoff is generally low in phosphorus (see Section 6.2.7). In the wet season, most runoff is surficial, which results in less opportunity for the chemical "seiving" processes to take place. Modification of water quality continues to occur within the river channel, however, for example through the adsorption of $PO_4^{\equiv}$-P onto particulate matter, the uptake of $PO_4^{\equiv}$-P by periphyton (attached algae) or mosses (Keup 1968), denitrification (Duff et al. in press) and nitrogen fixation (e.g. by epiphytic bacteria or mosses, Triska et al. 1984).

In the foregoing sections, the water quality of the principal rivers in El Cajón area has been discussed in some detail, with special attention being paid to nitrogen and phosphorus in view of their importance to reservoir productivity. The present section provides a brief, comparative summary of some of the main points discussed previously. Much of the water quality data is summarized in Fig. 6.1 and Table 6.4 presents mean parameter values and coefficients of variation (an indicator of temporal variation) for the R. Humuya at El Cajón.

Ca^{++} and HCO_3^- dominate the dissolved load of the rivers in the El Cajón area, indicating the importance of watershed soils and geology (as opposed to precipitation) in determining water quality (Gibbs 1970).

The chemical composition of the Humuya and Sulaco rivers was similar although some consistent differences were noted, for example lower base-level (dry season) $PO_4^{\equiv}$-P concentrations in the R. Sulaco. The R. Yure, however, was more dilute in terms of its total ionic content (i.e. conductivity), especially the calcium, magnesium and bicarbonate (alkalinity) components. Wet season concentrations of suspended solids and of nutrients associated with these sediments (iron and particulate phosphorus) were much lower in the R. Yure than in the R. Humuya and Sulaco. Levels of dissolved inorganic nitrogen (NO_3-N and NH_4-N) and $PO_4^{\equiv}$-P were similar in all three of the main rivers, as were concentrations of SiO_2. NO_3-N concentrations of the small, higher elevation streams flowing into L. Yure were higher than those at any of the other stations monitored, with the exception of the R. Chiquito, a small river which receives sewage discharge from the city of Comayagua. This river also exhibited high NH_4-N and $PO_4^{\equiv}$-P levels.

Temporal variation was greatest for those water quality parameters associated with erosional input of material from the watershed, i.e. suspended solids, total phosphorus and iron. These all increased by at least an order of

Table 6.4: Mean values and coefficients of variation for water quality parameters, 1979 - 1982, R. Humuya at El Cajoń.

Tabla 6.4: Valores promedios y coeficientes de variacioń para los parametros de calidad de aqua, R. Humuya en El Cajoń, 1979-1982.

Parameter		Mean	*C.V. (%)	No. of Observations
Temperature (^oC)		25.3	11	123
Dissolved O_2 (mg ℓ^{-1})		8.2	9	107
Conductivity (μmho cm^{-1})		243	25	121
pH		7.6	6	48
Alkalinity (mg ℓ^{-1} $CaCO_3$)		103.4	22	112
Turbidity (NTU)		173	171	111
Suspended Solids (mg ℓ^{-1})		317.6	182	94
% S.S. combustible		21	87	93
Total-P	(μg ℓ^{-1})	104	114	119
PO_4-P	(")	22	74	108
NO_3-N	(")	50	100	108
NH_4-N	(")	28	96	116
Fe	(mg ℓ^{-1})	1.18	149	123
Si	(")	11.53	28	122
Mg	(")	6.4	31	59
Ca	(")	25.8	45	59
Na	(")	9.2	20	59
K	(")	4.3	79	59

* Coefficient of variation = $\frac{\text{standard deviation}}{\text{mean}}$ x 100%

magnitude during the wet season in the Humuya and Sulaco rivers. Variation within the wet season was high however, reflecting the influence of individual storm events. Wet-dry season variation in these same parameters was much reduced in the R. Yure, presumably a result of its small size/catchment area and perhaps the land use practices within its watershed.

Conductivity, alakalinity, Ca^{++} and, usually, Na^{+} concentrations decreased from dry to wet seasons, indicating a dilution of river water by surface runoff. NO_3-N and $PO_4^{\equiv}$-P concentrations generally increased in the wet season while those of SiO_2, K^{+} and Mg^{++} either maintained fairly uniform levels or exhibited different behavior depending on the sampling station.

The relationships between nutrient concentrations and river discharge rates are illustrated for the R. Humuya at El Cajón and the R. Yure at Yure in Figs. 6.7, 6.10, 6.13 and 6.14. Either the relation is positive (e.g. phosphorus in R. Humuya, and iron), negative (e.g. phosphorus in R. Yure and calcium) or absent (e.g. silica).

Studies elsewhere (e.g. Bond 1979) have found that, although there is often only a weak relationship between discharge and concentration, a plot of logarithmic concentration against logarithmic discharge, with points being joined in a temporal sequence, may produce a trajectory which shows a clear seasonal cycle in the concentration/discharge relationship. Trajectories were found to often be characteristic for specific ions.

Distinct trajectories could not be generated from data collected in the present study, however. Nutrient and suspended sediment concentrations at a particular river discharge rate usually differ depending on whether the river level is rising or falling, i.e. on which "side" of the peak in river level the sample was collected. Higher concentrations (discharge-specific) are usually associated with increasing river levels. The often rapid fluctuations in river levels in the El Cajón area during the wet season meant that sampling was carried out at times on a rising and at times on a falling water level. This acted to increase the variance associated with concentration/discharge relationships and to reduce the chance of observing definite cyclical trajectories of the type mentioned above.

7. LAGO YURE

7.1 INTRODUCTION

The next three sections of this report discuss in detail the studies carried out on two lakes in the El Cajón area -- L. Yure and L. de Yojoa (see plate 7.G). As already explained, these two contrasting systems represent an invaluable foundation, not only for providing laboratory staff with broad experience in practical limnology, but also for ensuring the overall integration of the studies on the rivers of the El Cajón watershed into a reservoir-oriented framework.

This section presents the results of the limnological work carried out on L. Yure. Section 8 presents the data collected from L. de Yojoa. In Section 9 there is a discussion of some of the important ways in which the two lakes differ limnologically. This discussion is then extended to the future limnology of the El Cajón reservoir.

7.2 SITE DESCRIPTION

Lago Yure is the reservoir that was formed in 1978 from the diversion of the headwaters of the R. Yure into L. de Yojoa as part of the program for increasing the power generation capacity of the Cañaveral/Río Lindo hydroelectric complex. It is a small, steeply-sided, dendritic reservoir with three principal branches (Fig. 7.1). Morphometric characteristics of L. Yure are presented in Table 7.1. The lake's hypsographic (depth-area) curve illustrates the steep morphology of the reservoir basin (Fig. 7.2). The curve represents the relative proportion of the bottom area of the lake, which is below the depth under consideration.

Although much of the watershed of the three main streams flowing into L. Yure is forested (see plate 7.H), an increasing area is being cleared for

7-179

Pla . a a lake in vo d r El Caj

F . n lago b l e e iagos de E C j n

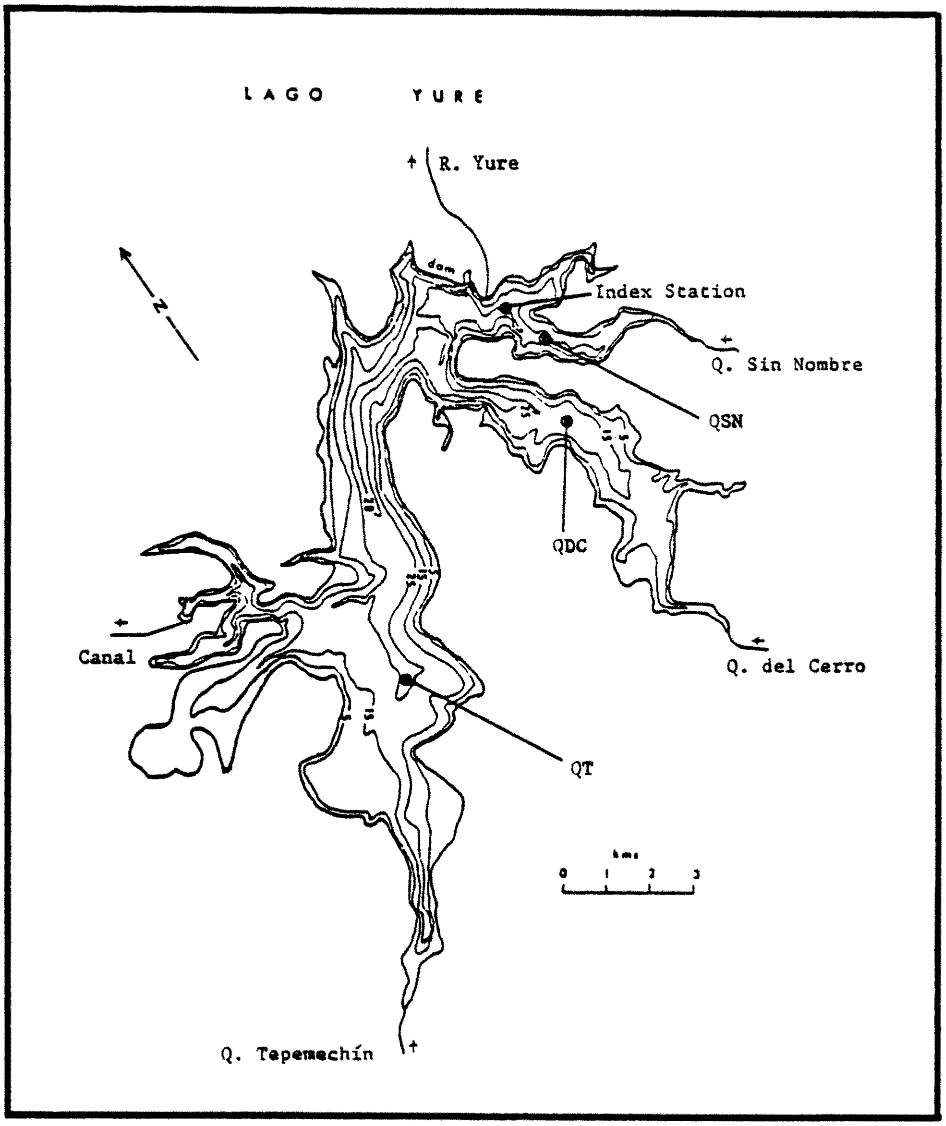


Figure 7.1: Map of L. Yure, showing principal sampling stations.

Figura 7.1: Mapa del L. Yure, señalando las principales estaciones de muestreo.

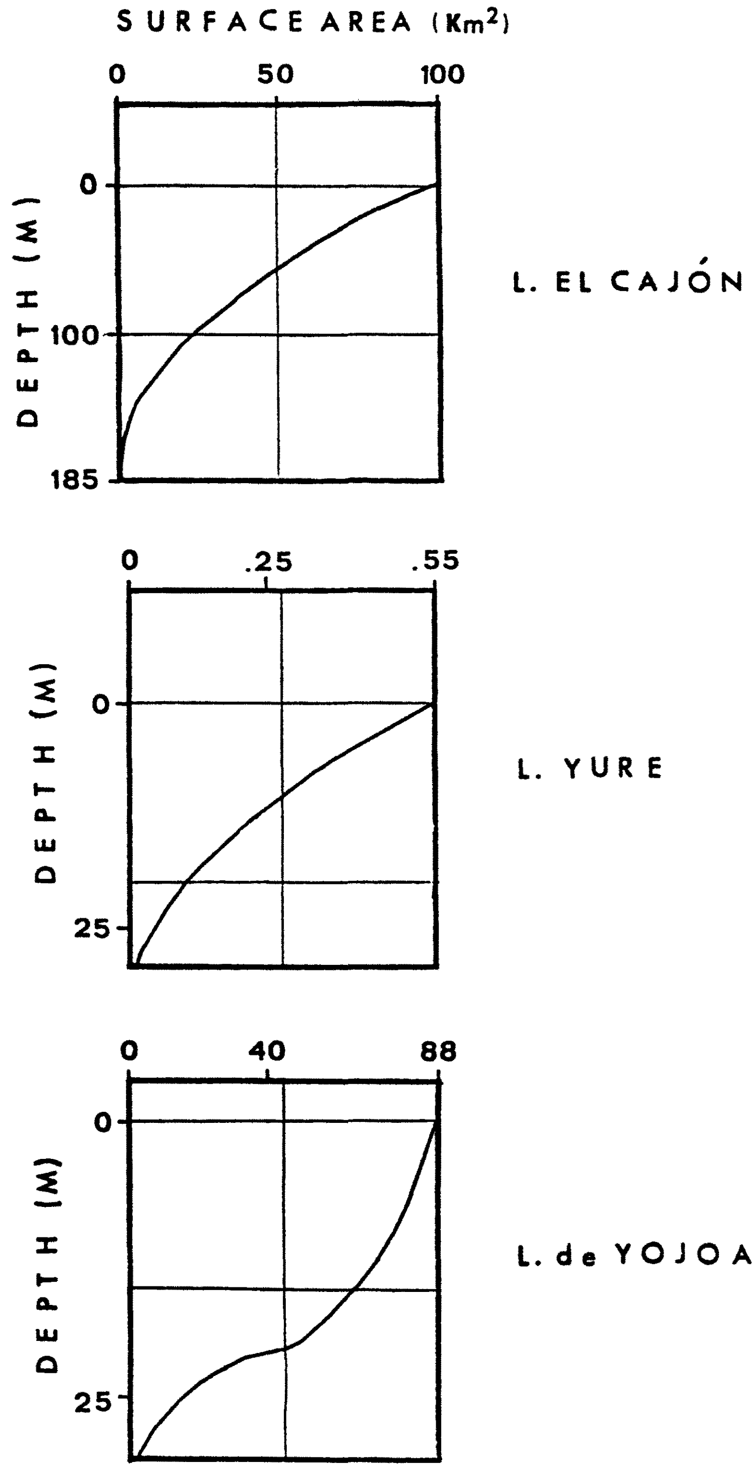


Figure 7.2: Hypsographic curves for L. El Cajón, L. Yure and L. de Yojoa.

Figura 7.2: Curva hipsográfica de los lagos El Cajón, Yure y Yojoa.

Table 7.1: Morphometric characteristics of L. de Yojoa, L. Yure, and the El Cajón reservoir.

Tabla 7.1: Características morfométricas del L. de Yojoa, L. Yure y el embalse de El Cajón.

Parameter	L. de Yojoa	L. Yure	L. El Cajón*				
			T	H	S	Y	C
Area (km^2)	88.0	0.55	92.0	33.4	50.0	7.1	1.7
Perimeter (km)	54	11.8	465.7	206.8	210.7	40.1	8.1
Shore-line development	1.6	4.5	13.7	10.1	8.4	4.2	1.8
Volume ($x\,10^6\,m^3$)	792.9	7.7	4500.0	-	-	-	-
Maximum depth (m)	26	28	185	-	-	-	-
Mean depth (m)	10	14	49	-	-	-	-
Mean retention time (yr)	2.5	0.2	0.9	-	-	-	-
Max. surface elevation (masl)	638	655	285	-	-	-	-
Area of drainage basin (km^2)	337	35	8320	3388	4618	290	24

* T = Entire El Cajón reservoir
H = Humuya branch
S = Sulaco branch
Y = Yure branch
C = Section between Humuya/Sulaco confluence and dam wall.

cultivation, often on very steep slopes. There are few families living in the zone immediately surrounding the reservoir, however (see plate 7.I).

The outflow from L. Yure is usually via the canal leading to L. de Yojoa; only after very heavy storms does water pass over the dam spillway and into the R. Yure (see plate 7.J). The difference between maximum and minimum lake levels in 1981 and 1982 was about 2 m, but between mean dry and wet season levels it was about 0.5 m (Fig. 7.3). Changes in water level could be very rapid, reflecting the relatively small surface area of the lake and short retention time.

The index station was located off the spillway in one of the deepest parts of the lake. Because of the relationship between the main inflows to the lake and the canal outflow, it was impossible to choose an index station located in deep water which would have been fully representative of the whole lake (water from Q. Tepemechín infrequently reached the northern end of the reservoir, for example). The question of spatial heterogeneity in this dendrictic reservoir was addressed with synoptic surveys which are discussed more fully below.

The retention time of about 2 1/2 months (Table 7.1) is a theoretical one, calculated by dividing lake volume by the estimated annual discharge of the three main influent streams. The actual residence time of any particular "parcel" of water varies depending on lake morphometry, stream flow and the thermal structure of the lake.

The often steeply-sloping shoreline of the lake does not provide favorable habitat for macrophyte plant development. In the first two years of the study, almost no rooted aquatic plants were observed. However, during 1982 there was increasing development of beds of Chara (Fig. 7.4) and filamentous algae, primarily the desmid Desmidium but also Spirogyra, Mougeotiopsis, and the blue-green Spirulina. These filamentous algae grew both on the substrate, which is a

Plate 7.H. Lago Yure, looking east.
Foto 7.H. Lago Yure, en dirección del este.

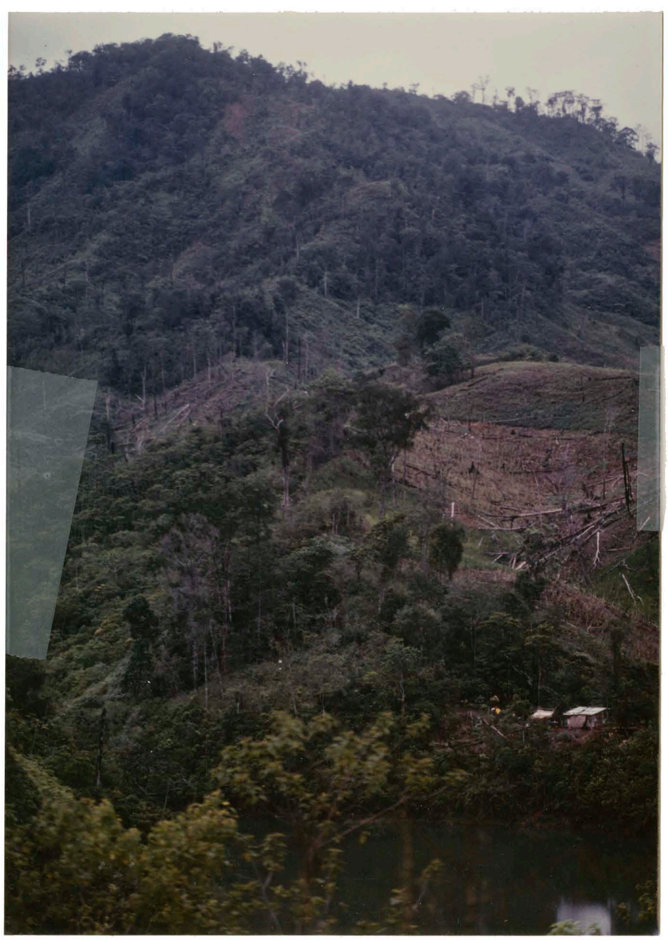


Plate 7.I. Lago Yure, showing hills to the east and forest clearance.
Foto 7.I. Lago Yure, ilustrando montañas al este y deforestación.

Plate 7.J. Lago Yure (foreground) and lago de Yojoa (background) showing canal which connects the two lakes.

Foto 7.J. Lago Yure (abajo) y lago de Yojoa (arriba) mostrando el canal que conecta los dos lagos.

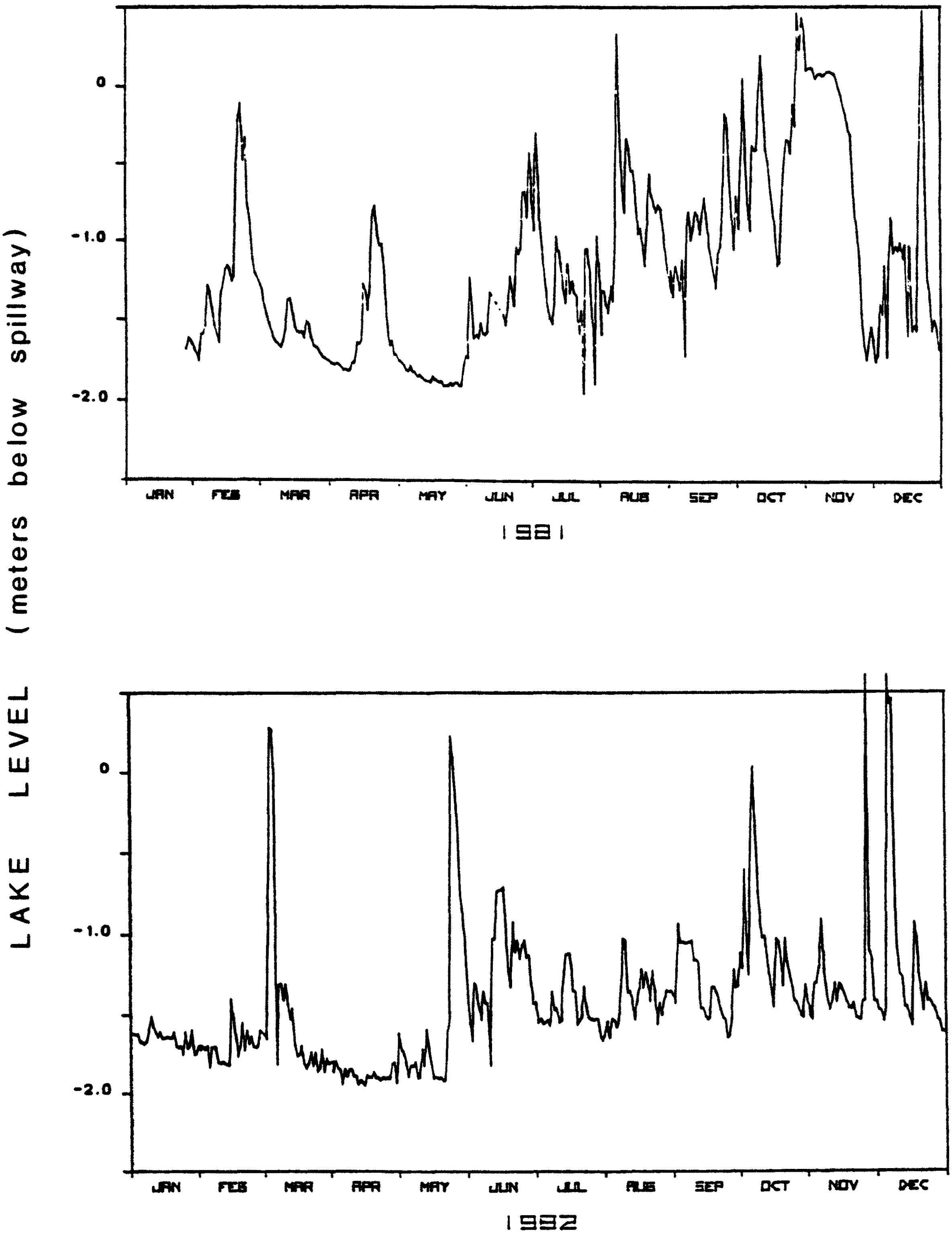


Figure 7.3: L. Yure water levels, 1981-1982.

Figura 7.3: Niveles del L. Yure, 1981-1982.

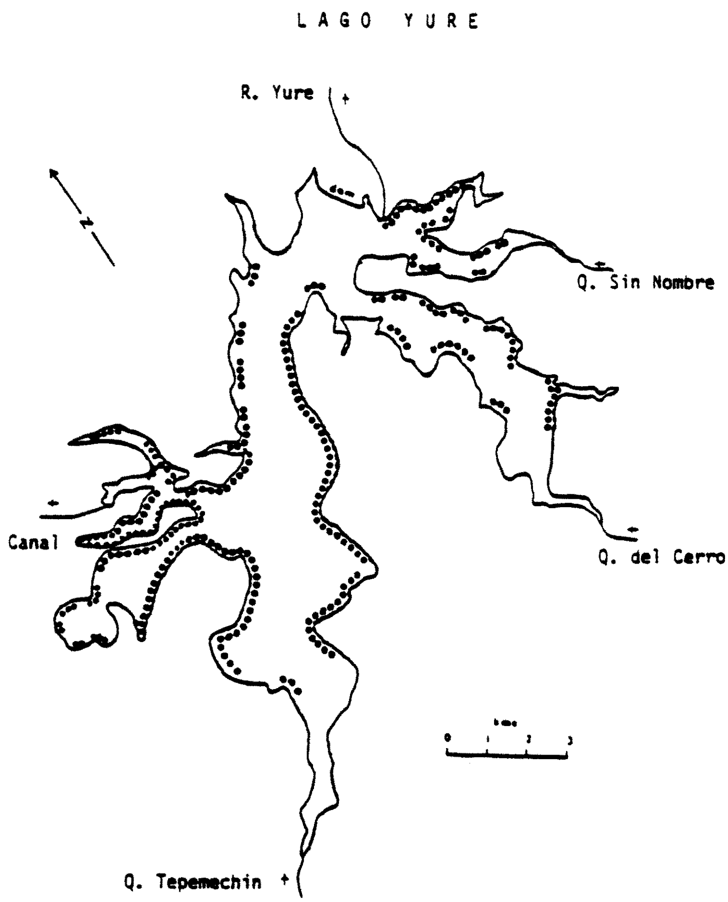


Figure 7.4: Distribution of the macroalga <u>Chara</u> in L. Yure, December 1982.

Figura 7.4: Distribución de la macroalga <u>Chara</u> en el L. Yure, diciembre de 1982.

mixture of fine silt and clay, and on the *Chara* plants themselves. In a few areas there were mats of filamentous and pennate diatoms, and clumps of the grass *Paspalum*. Although no biomass measurements were made, *Chara* was obviously the biomass dominant of the substrate-associated plant community. It was confined to depths of less than about 0.3 m.

Climate: Total annual rainfall in the area (as measured at Santa Elena, about 1 km from the lake) was 3010 mm and 3071 mm in 1980 and 1981 respectively. There was measurable precipitation on an average of 250 days during the year. The monthly distribution of rainfall is shown in Fig. 7.5.

Average daily incident solar radiation in 1980, 1981 and 1982 was 372, 364, and 361 langleys (calories/cm^2), respectively. As Fig. 7.6b demonstrates, there was considerable within-month (between-day) variation in incident radiation. These fluctuations were greatest, both in absolute terms and as a percentage of the monthly means, during the period from December-March. Fig. 7.6a presents monthly averages of daily solar radiation from October 1979 to December 1982. Other meteorological information is presented in Fig. 7.5 (adapted from Motor Columbus 1977).

7.3 PHYSICAL LIMNOLOGY

7.3.1 *Thermal Regime*

The thermal regime of a lake is one of the most important factors influencing both its water quality and biota. Temperature profiles recorded from the index station at L. Yure are presented in three ways. First, the raw data are reproduced in Appendix 10. Second, in Fig. 7.7, there is a sequence of profiles from 20 dates during 1981, which demonstrate the seasonal pattern of stratification/mixing and its effect on dissolved oxygen concentrations. Third, the entire data record from 1979 to 1983 is summarized in a composite depth-time

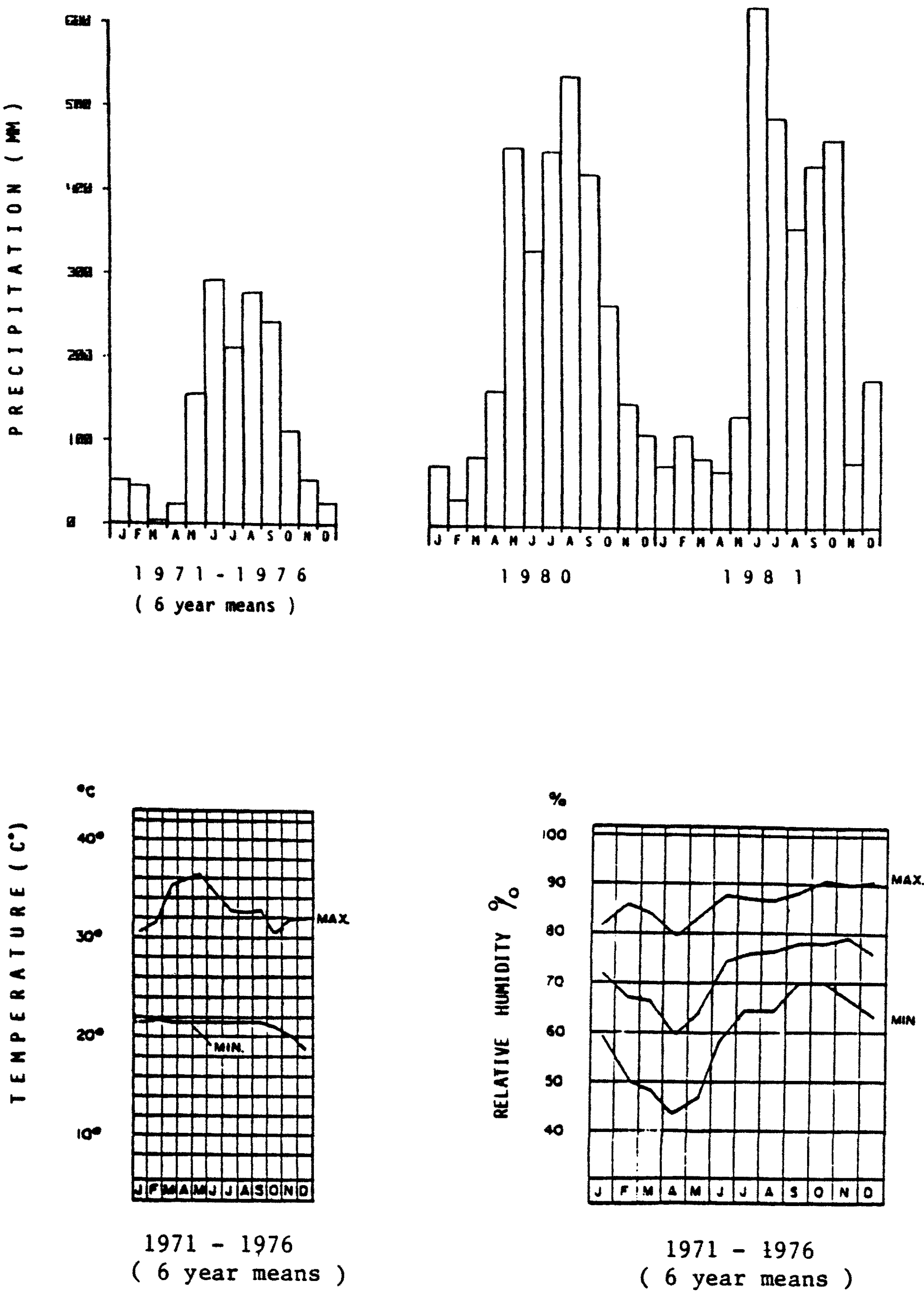


Figure 7.5: Precipitation, air temperature and relative humidity at Santa Elena, (about 1 km from L. Yure).

Figura 7.5: Precipitación, temperatura atmosférica y humedad relativa en Santa Elena, (aproximadente 1 km del L. Yure).

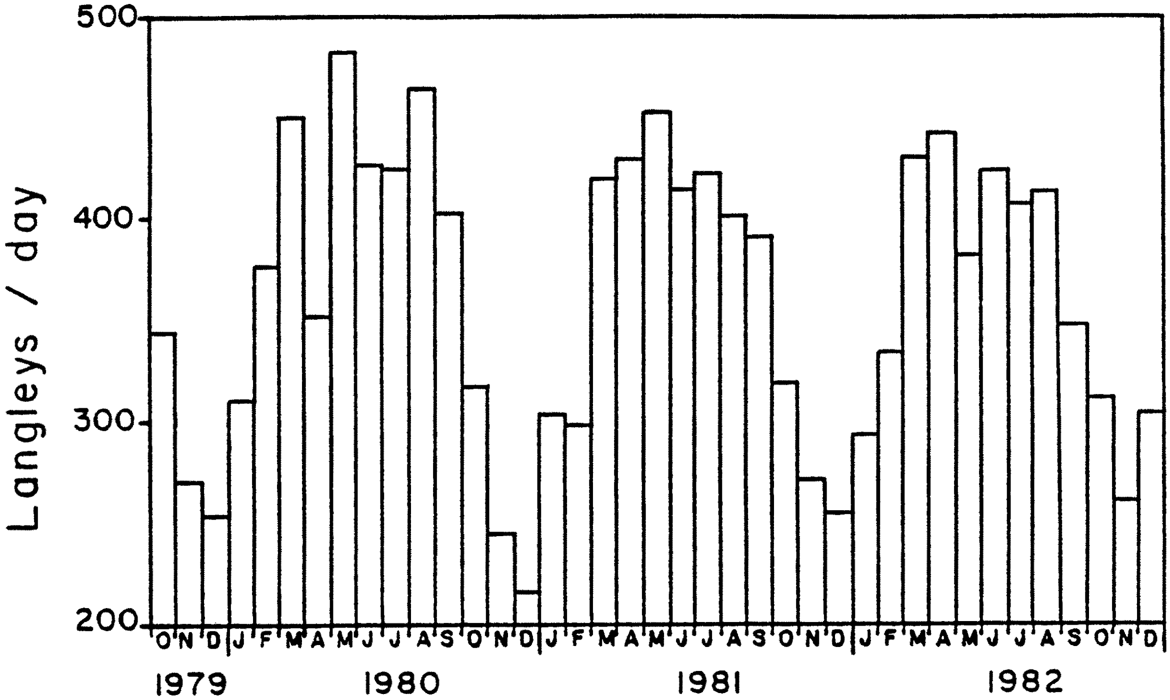


Figure 7.6 a: Mean daily solar radiation at Santa Elena, 1979-1982.

Figura 7.6 a: Promedio diario de radiación solar en Santa Elena, durante 1979-1982.

Figure 7.6 b: Daily variation in solar radiation at Santa Elena, 1980-1982.

Figura 7.6 b: Variaciones diarias en radiación solar en Santa Elena, durante 1980-1982.

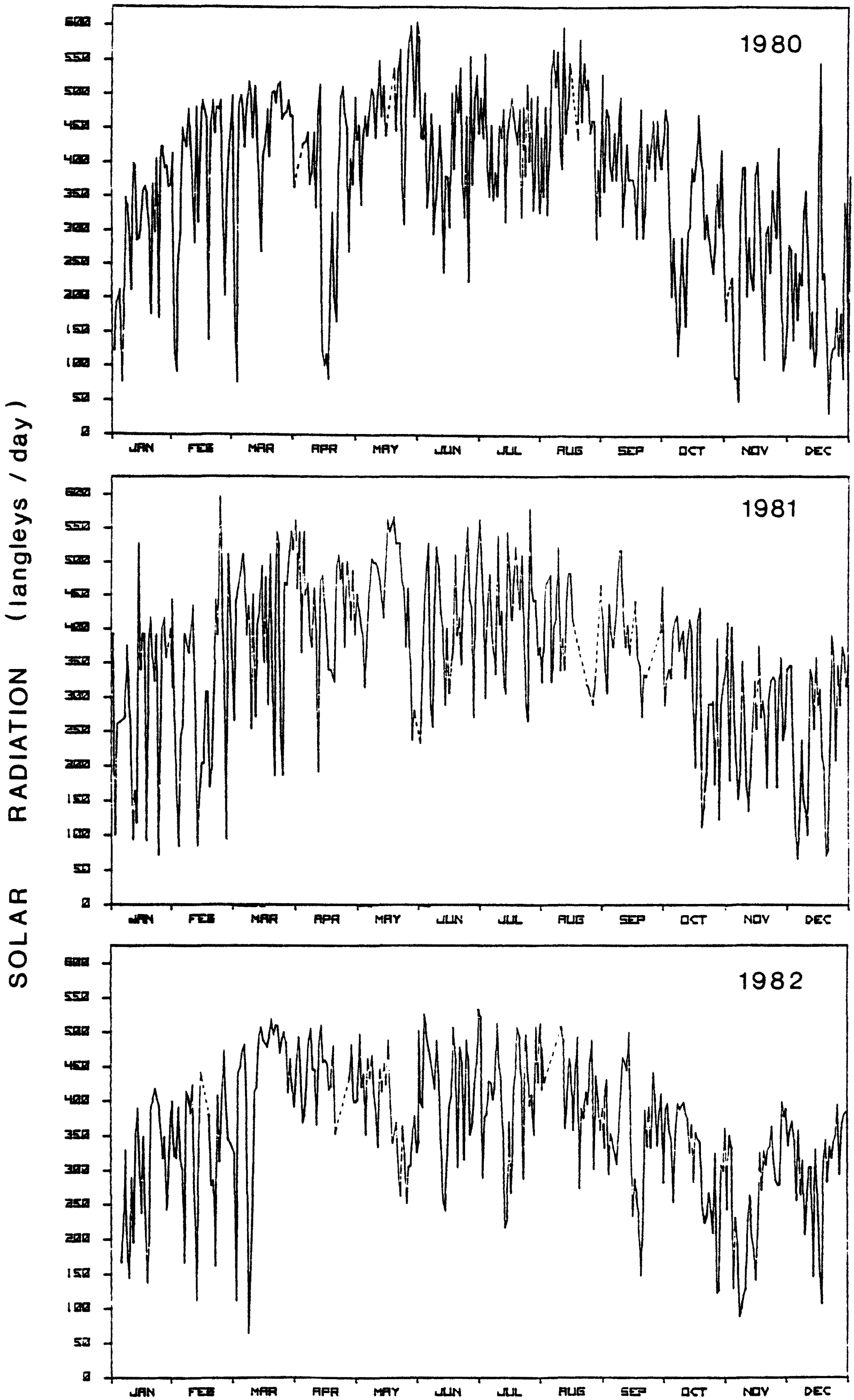

1980
1981
1982
SOLAR RADIATION (langleys / day)
0
50
100
150
200
250
300
350
400
450
500
550
600
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure 7.6 b

Figure 7.7: Profiles of dissolved oxygen and temperature at the L. Yure index station, 1981.
(Arrows represent the temperature of Quebrada del Cerro on the sampling date -- see text for further description.)

Figura 7.7: Perfiles de oxigeno y temperatura en la estacion indice del L. Yure, 1981.
(Las flechas representan la temperatura de la Quebrada del Cerro en la fecha de muestreo -- ver texto para mayor descripcion.)

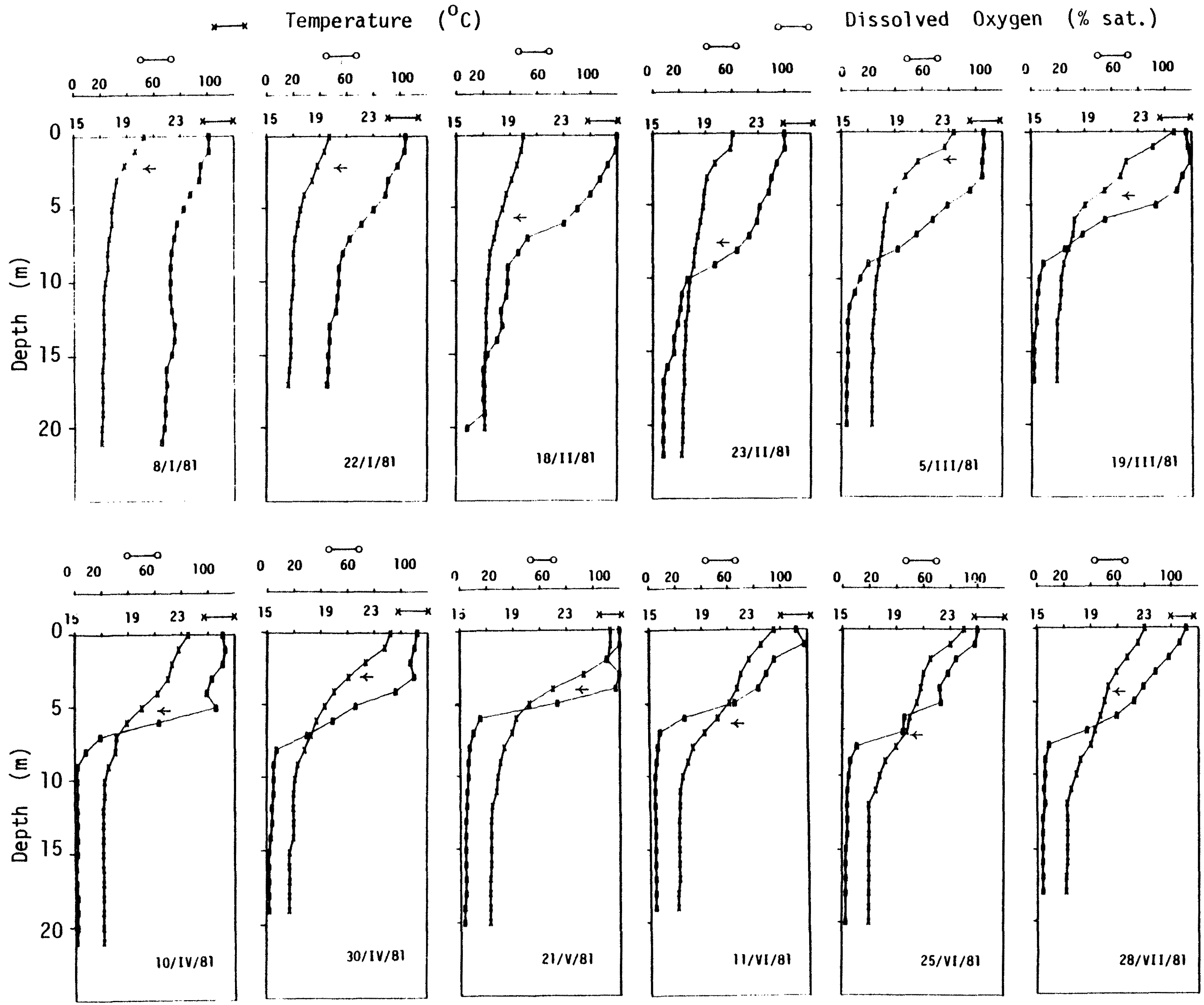

Temperature (°C)
Dissolved Oxygen (% sat.)
0 20 60 100
15 19 23
Depth (m)
0
5
10
15
20
8/I/81
22/I/81
18/II/81
23/II/81
5/III/81
19/III/81
10/IV/81
30/IV/81
21/V/81
11/VI/81
25/VI/81
28/VII/81

Figure 7.7

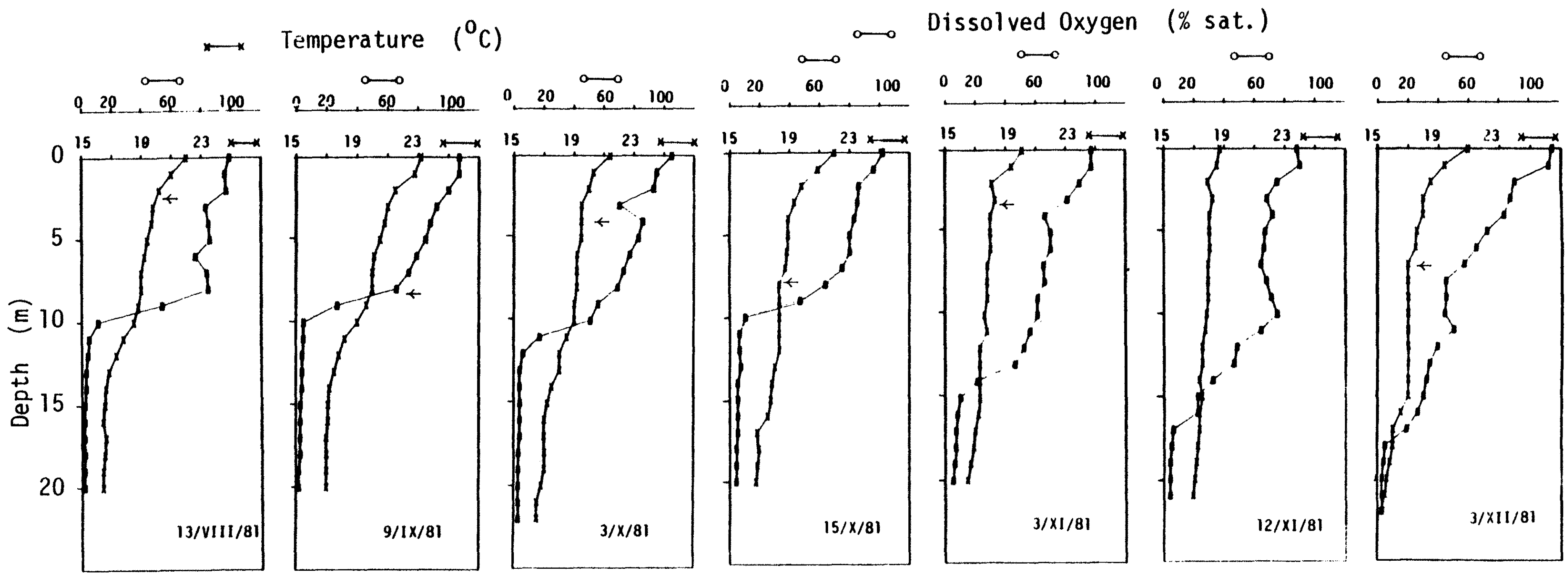


Figure 7.7 (cont.)

diagram (Fig. 7.8). In this figure, individual lines (isotherms) represent series of points in space (depth) and time which have equal temperature. Closely spaced lines therefore represent steep temperature gradients.

Since the density of water is inversely proportional to its temperature (above 4^{o}C), solar heating of a lake tends to decrease the density of the surface layers, making them more buoyant and more resistant to wind mixing as temperatures increase. Wind and solar heating (plus other factors such as surface cooling and inflowing streams) are therefore factors which act against each other in determining the depth to which water is circulated (mixed). When the mixing forces are sufficiently large relative to the buoyancy forces, a lake mixes from top to bottom and is isothermal. However, when this is not so, part of the lake, the hypolimnion, is removed from circulation and mixing only occurs in the upper layer, or epilimnion. A zone of relatively rapid temperature change with depth separates these two layers. This zone of change is called the metalimnion. (The thermocline properly refers to the plane at which the temperature change with depth is greatest and has classically been restricted to a change of 1^{o}C per meter of depth). At the relatively high temperatures characteristic of L. Yure and Yojoa, only a small temperature difference is necessary to provide a sufficiently high density gradient to result in stable stratification. Fig. 7.9 illustrates the terms used above.

L. Yure is a warm, monomictic lake according to the classification of Hutchinson (1957) that is, it never cools to below 4^{o}C and it mixes once a year. Surface temperatures varied from about 20^{o}C in December/January to 26^{o}C in June. Bottom temperatures remained at about 17^{o}C during the whole year. Figs. 7.7 and 9.1 clearly show the seasonal pattern of stratification. The lake was essentially isothermal in January 1981. (Note that there was often a marked thermal discontinuity in the upper few meters, resulting from strong surface

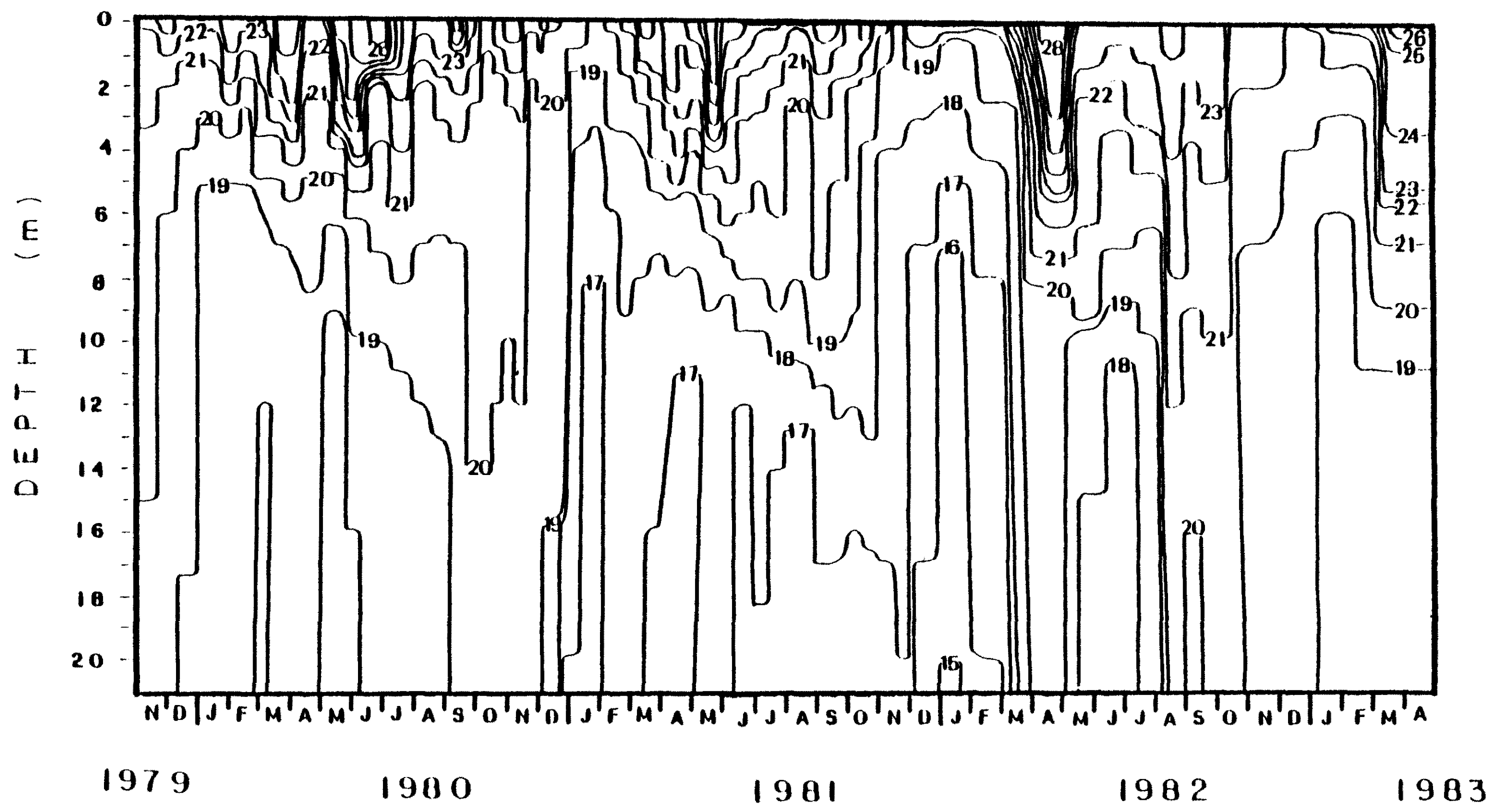


Figure 7.8: Depth-time diagram of isotherms in L. Yure, 1979-1983.

Figura 7.8: Diagramas isotérmicas de profundidad-tiempo en el L. Yure, 1979-1983.

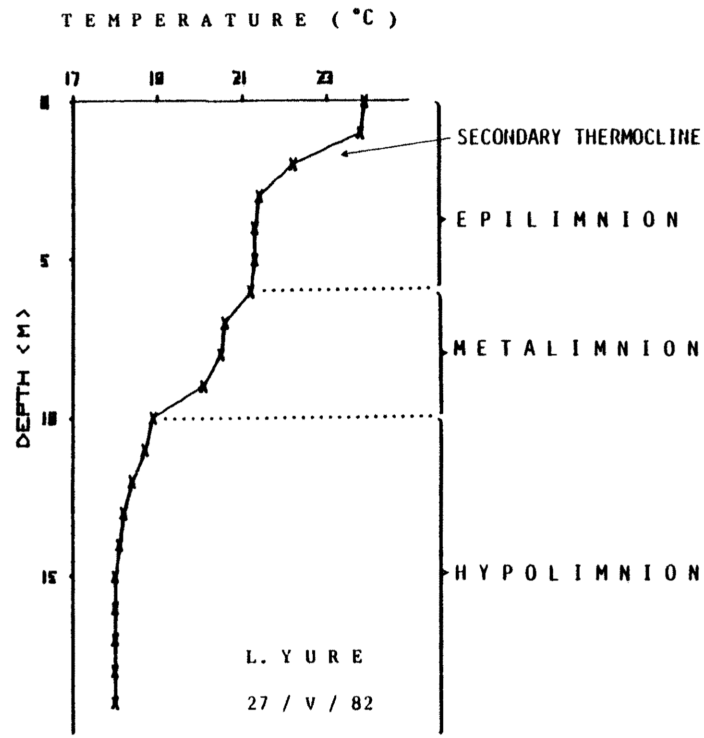


Figure 7.9: Temperature profile at the L. Yure index station on 27/V/82, illustrating terminology used in the text.

Figura 7.9: Perfil de temperatura en la estacion índice del L. Yure en la fecha 27/V/82, ilustrando la terminología usada en el texto.

heating and insufficient wind mixing. This generally broke down at night, however, as the surface layers re-radiated heat to the atmosphere). By February, a slight temperature discontinuity had developed at 15 m. By April the primary thermocline was at 10 m, and had risen to about 7 m by June.

At this time, increased wind mixing associated with the wet season storms began to erode the thermocline to a deeper level. However it wasn't until the end of the year that isothermal conditions were reinstated. Thus, although wind mixing was important in determining thermocline depth during much of the year, complete circulation was only attained in December and January when air temperatures were low enough at night to result in significant cooling of the surface water layers by back-radiation of previously stored heat. Cooling increased the density of the surface water which, by sinking, promoted mixing. The reduction in the density gradient between surface and bottom water at this time also assisted deep mixing by wind stress.

Since stratification removes hypolimnetic water from contact with the atmosphere, and light penetration is often not sufficient for significant photosynthetic activity within the hypolimnion, oxygen concentrations usually decrease below the thermocline. It is often easier to trace a stratification sequence using oxygen concentrations than using temperature (e.g. Fig. 7.7; see Section 7.4.2 for a further discussion of circulation and oxygen regime).

Temperature profiles at other stations in L. Yure (QSN, OdC and QT) were usually very similar to those at the index station and are therefore not presented here.

In many reservoirs, the density of major inflowing rivers can be important in influencing stratification patterns and nutrient profiles. Typically after entering a lake. river water flows along the depth stratum at which lake and river water have equal densities (e.g. Ford and Johnson 1981). If the river is carrying a low suspended sediment load, temperature is usually the principal factor influencing density. When river temperatures are lower than lake temperatures, river water will tend to move through the reservoir along the former river bed; this is termed underflow. If its velocity is high enough, the river continues for some distance into the reservoir at the depth of entry and then rather sharply dips down to the depth of equal density. This occurs where the buoyancy forces of the flow exceed the inertial forces; the location is called the plunge point. The plunge point is sometimes made visible by sharp changes in turbidity or accumulations of floating debris. When the river temperature is such as to cause it to flow at mid-depths or through the surface layers, then interflow or overflow, respectively, occur. High sediment loads increase water density so that, with turbid rivers, depth of flow does not depend solely on temperature. Channel morphology and river velocity are important factors which determine the extent of mixing that occurs between river and lake water, and thus how far into the reservoir the inflowing water exists as a discrete flow.

This phenomenon can be very important in terms of reservoir productivity since it may determine whether or not nutrients in the inflowing rivers become available to phytoplankton, which are often most abundant in the epilimnion (for further information see section 9).

The temperatures of the main tributaries to L. Yure varied seasonally between about 19 and 24^{o}C. In Fig. 7.7, the arrow on each temperature profile indicates the depth at which lake temperature equalled the temperature of Q. del Cerro on that date. (Index station temperature profiles were usually very similar to those at the QdC station). Assuming that temperature was the principal factor determining depth of flow into the lake (which was probable since the suspended sediment load of these streams was usually very low), it is evident from Fig. 7.7 that the tributaries usually flowed along the lower part of the epilimnion. Q. Tepemechín was usually 1-2^{o} warmer than Q. del Cerro and so presumably also exhibited epilimnetic interflow. Of course, since the discharge rates of these streams were not normally very high, it is likely that the stream water was, within a fairly short distance, entrained into the epilimnetic circulation and ceased to exist as a discrete water mass. Examples of distinct underflows are discussed in section 7.4.2.

7.3.2 Light Penetration

Light penetration was measured by two methods, a Secchi disc and a submersible photometer. Seasonal trends in Secchi depth are shown in Fig. 7.23.

A more detailed documentation of light penetration was obtained with the submersible photometer. As light passes through water and is absorbed and refracted by particulate matter and the water molecules themselves, it decreases exponentially with depth according to the general expression:

$$L_z = L_o\, e^{-nz}$$

where L_z = light at depth z

L_o = light at the surface

n = a coefficient of extinction

and e = base of natural logarithms.

The coefficient n characterizes the degree to which the amount of light is reduced per unit depth. Low values of n indicate low turbidity. This is illustrated in Fig. 7.10, where the light profile at L. Yure index station on 8/I/81 is plotted both as % surface light and as log % surface light. (A logarithmic transformation of the above equation results in an equation for a straight line whose slope is n). Note that on this date, the semi-logarithmic plot demonstrated that the coefficient n varied with depth, indicating that there were three water "layers" of differing absorbance. The most turbid water (also the warmest) was at the surface.

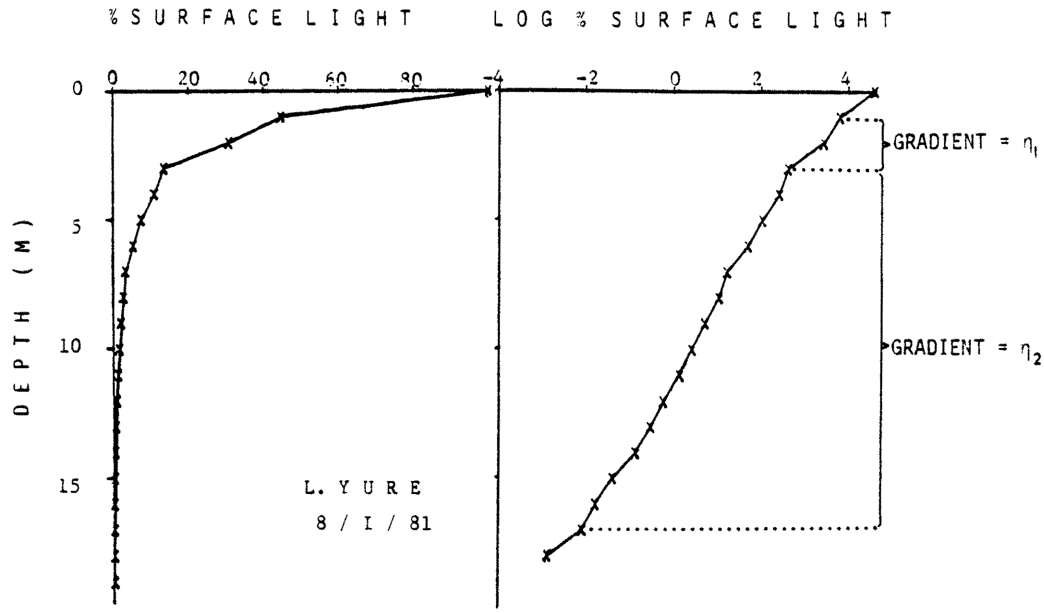


Figure 7.10: Light profiles at the L. Yure index station on 8/I/81, illustrating the calculation of extinction coefficients (see text for further explaination).

Figura 7.10: Perfiles de luz en la estación índice del L. Yure en la fecha 8/I/81, ilustrando los cálculos de coeficiente de extinción (ver texto para mayor explicicación).

Extinction coefficients for L. Yure are presented in Table 7.2, and are shown graphically in Fig. 7.11. Fig. 7.22 presents a series of light profiles from 1981. On dates when n varied with depth, average values for the entire water column were used for Fig. 7.11. (Note that extinction coefficients have only been calculated for 1 m and below. This is because 0 m light was taken as the deck-cell reading, and thus a proportion of the difference between 0 and 1 m light levels was due to reflection at the lake surface, and not absorbtion by the water. The gradient of the light profiles between 0 m and 1 m therefore appears too steep).

Seasonal trends in extinction coefficients were, not surprisingly, similar to those for Secchi depth (although numerically inverse; Fig. 7.12). Lowest values of n (clearest water) were observed during December-April and highest values (most turbid water) during the wet season. The wet season peaks, however, were bimodal, corresponding to, and possibly lagging slightly behind, the bimodal pattern in rainfall. Increased turbidity during the wet season was primarily due to higher sediment loading from the inflowing streams, but also had a biogenic component (primarily phytoplankton). The % ash-free dry weight (equal to organic matter) of suspended solids in the canal outflow from the lake had a dry season (January-April) mean of 59 ($\pm$ 30)% and a wet season (June-September) mean of 30 ($\pm$ 11)% indicating the importance of the abiogenic (inorganic) component of turbidity during the wet season (Table 7.3a).

From Fig. 7.11, it is evident that there was a decrease in the maximum and average wet season values of n between 1980 and 1982. Furthermore, the period of high n values appears to have gradually moved to earlier in the year. It is impossible to know if the latter observation represents a real phenomenon or not, since sampling was not carried out frequently enough during 1982 to allow sufficient confidence in the observed trends. A similar problem applies to the

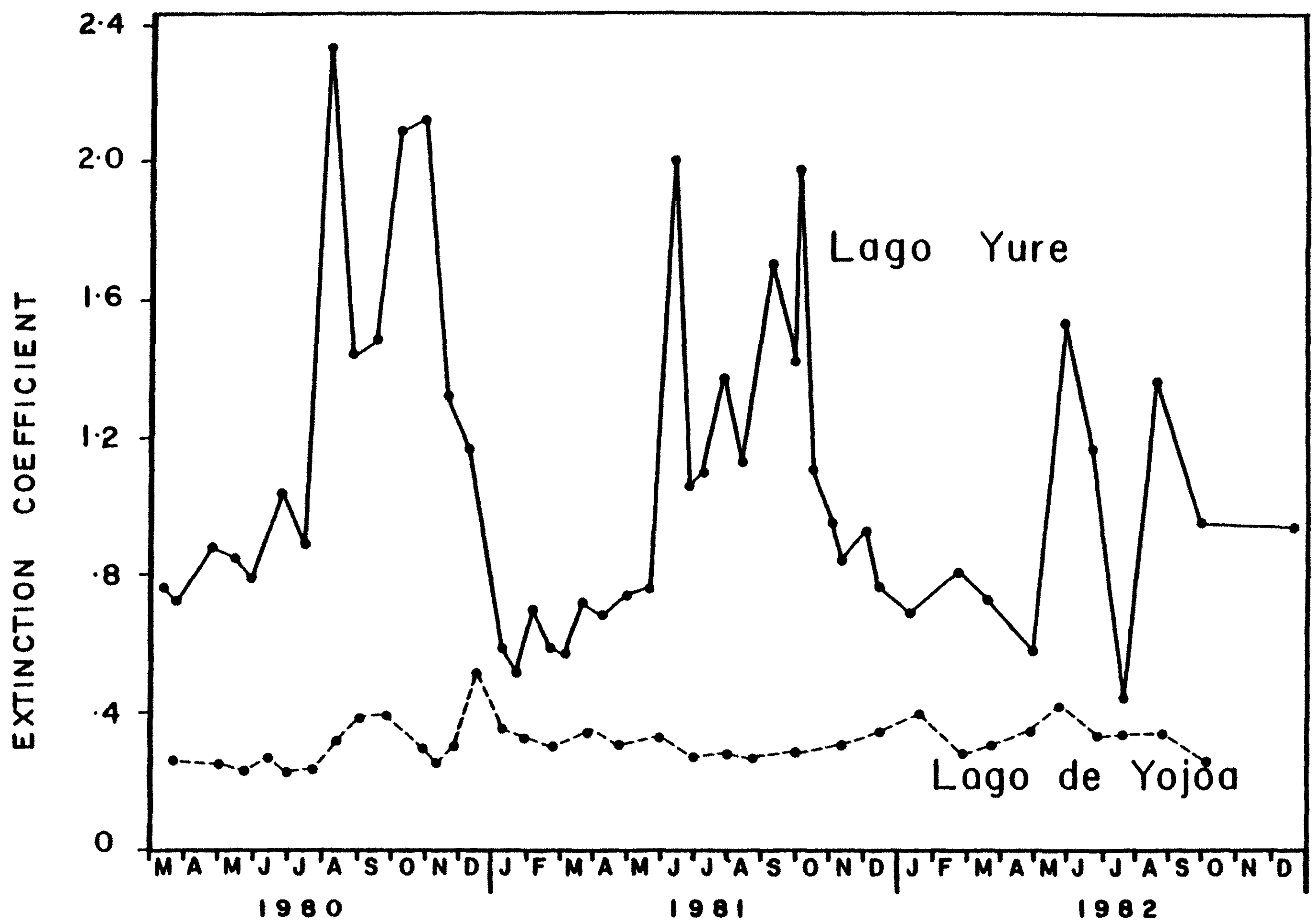


Figure 7.11: Seasonal variation of extinction coefficients, L. Yure and L. de Yojoa.

Figura 7.11: Variación estacional de coeficientes de extinción en el L.Yure y L. de Yojoa.

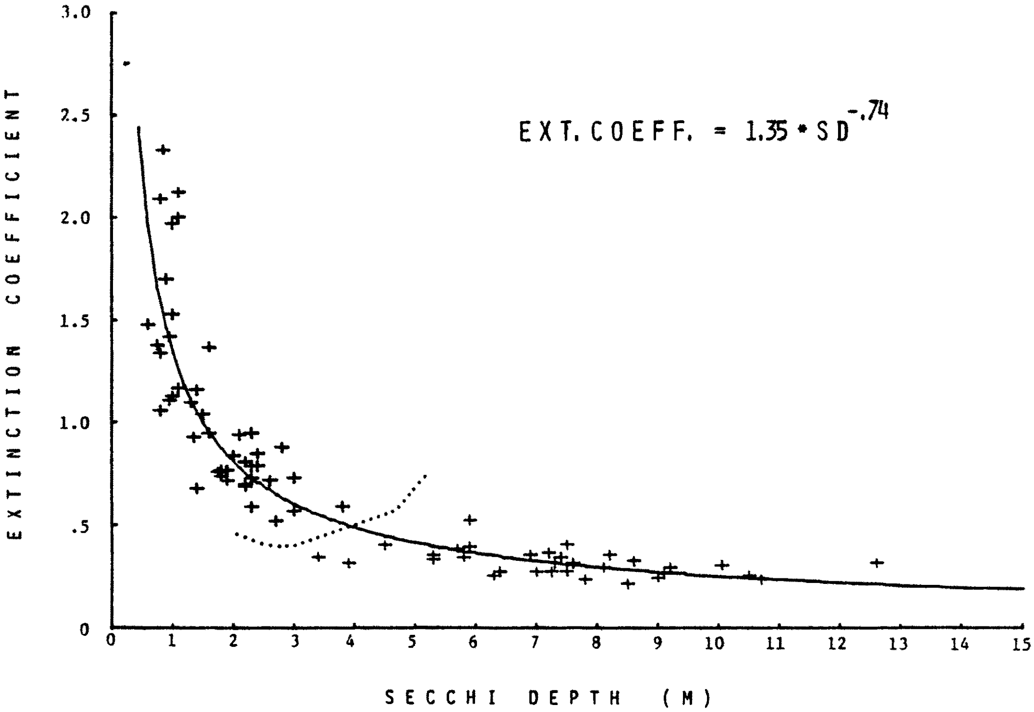


Figure 7.12: Relationship between Secchi depth and extinction coefficient.
(Points to the left of the dotted line represent data from L. Yure, those to the right represent data from L. de Yojoa).

Figura 7.12: Relacioń entre la profundidad de Secchi y coeficiente de extincioń.
(Puntos a la izquierda de la linea de puntos representan datos del L. Yure, aquellos a la derecha representan datos del L. de Yojoa).

Table 7.2: Extinction coefficients, L. Yure index station.

Tabla 7.2: Coeficientes de extinción en la estación índice del L. Yure.

Date	Depth	η	
13/III/80	1-6	.77	
26/III/80	1-2	1.10	} $\bar{\eta}$ = .72
	2-6	.65	
24/IV/80	1-8	.88	
15/V/80	1-6	.85	
29/V/80	1-3	.62	} $\bar{\eta}$ = .79
	3-7	.84	
26/VI/80	1-4	1.04	
16/VII/80	1-3	1.01	} $\bar{\eta}$ = .79
	3-6	.64	
7/VIII/80	1-3	2.33	
28/VIII/80	1-4	1.44	
18/IX/80	1-3	1.48	
9/X/80	1-3	2.09	
30/X/80	1-3	2.12	
20/XI/80	1-3	1.55	} $\bar{\eta}$ = 1.34
	3-6	1.24	
10/XII/80	1-3	.92	} $\bar{\eta}$ = 1.16
	3-6	1.36	
8/I/81	1-4	.80	} $\bar{\eta}$ = .59
	4-12	.54	
22/I/81	1-11	.52	
6/II/81	1-3	.87	} $\bar{\eta}$ = .70
	3-7	.59	
23/II/81	2-7	.59	
5/III/81	1-11	.57	
19/III/81	1-5	.77	} $\bar{\eta}$ = .72
	5-8	.51	
20/III/81	1-5	.82	} $\bar{\eta}$ = .73
	5-7	.51	
21/III/81	1-3	.79	} $\bar{\eta}$ = .69
	4-6	.60	
10/IV/81	1-3	1.03	} $\bar{\eta}$ = .68
	3-5	.80	
	5-8	.46	
	9-11	.75	

Date	Depth	η	
30/IV/81	1-4	.85	} $\bar{\eta}$ = .74
	4-6	.58	
21/V/81	1-6	.76	
11/VI/81	1-4	2.00	
25/VI/81	1-5	1.06	
9/VII/81	2-5	.77	} $\bar{\eta}$ = 1.10
	5-7	1.46	
28/VII/81	1-4	1.11	} $\bar{\eta}$ = 1.38
	4-5	2.46	
13/VIII/81	1-4	1.28	} $\bar{\eta}$ = 1.13
	4-6	.85	
9/IX/81	1-3	1.70	
	3-4	4.45	
29/IX/81	1-4	1.42	
3/X/81	1-3	1.97	
15/X/81	1-3	1.11	
3/XI/81	1-4	.95	
12/XI/81	1-4	.84	
3/XII/81	1-2	1.35	} $\bar{\eta}$ = .93
	2-6	.86	
15/XII/81	1-4	.77	
12/I/82	1-3	.84	} $\bar{\eta}$ = .69
	3-7	.64	
23/II/82	1-5	.81	
18/III/82	1-6	.73	
29/IV/82	1-7	.58	
27/V/82	1-3	1.53	
22/VI/82	1-5	1.17	
20/VII/82	1-8	.44	
18/VIII/82	1-4	1.37	
28/IX/82	1-4	.78	} $\bar{\eta}$ = .95
	5-9	1.07	
22/XII/82	1-4	.65	} $\bar{\eta}$ = .94
	4-7	1.17	

interpretation of the apparent trend by decreasing mean wet season extinction coefficients. However, there does appear to be a relationship between this trend and lower primary productivity values during the 1982 wet season which possibly indicate reduced biogenic turbidity at that time. (See further, section 7.5).

The depth at which 1% of the incident surface light remains is usually considered as the compensation depth, i.e. where the amount of oxygen produced by photosynthesis equals the amount used in respiration. The region above the 1% light level is termed the euphotic zone. Its depth, relative to that of the epilimnion (mixed zone), can have a significant influence on levels of primary production (see section 9).

7.3.3 Turbidity

A series of turbidity profiles taken at the index station in 1981 is shown in Fig. 7.13. During the dry season, water turbidity was generally low, as has been previously indicated in the discussion of extinction coefficients. Wet season turbidity profiles were much more variable than those of the dry season, primarily a result of sediment loading from the tributaries (see plate 7.K). On 9/VII/81, for example, the highest observed turbidity value was at 6 m, and probably represented sediment entering the lake during a storm the previous day (c.f. Fig. 7.3). The temperature of Q. del Cerro and Q. Sin Nombre at that time was 20.2^{o}C, which meant that water from these streams would have initially moved through the reservoir at a depth of 5 m (or deeper, depending on the sediment load). This is in agreement with the turbidity profile of 9/VII/81.

Profiles of total phosphorus provide a similar representation of the entry and subsequent sedimentation of particulate matter in L. Yure (see section 7.4.3).

Seasonal variation in the % AFDW of suspended solids in the canal outflow

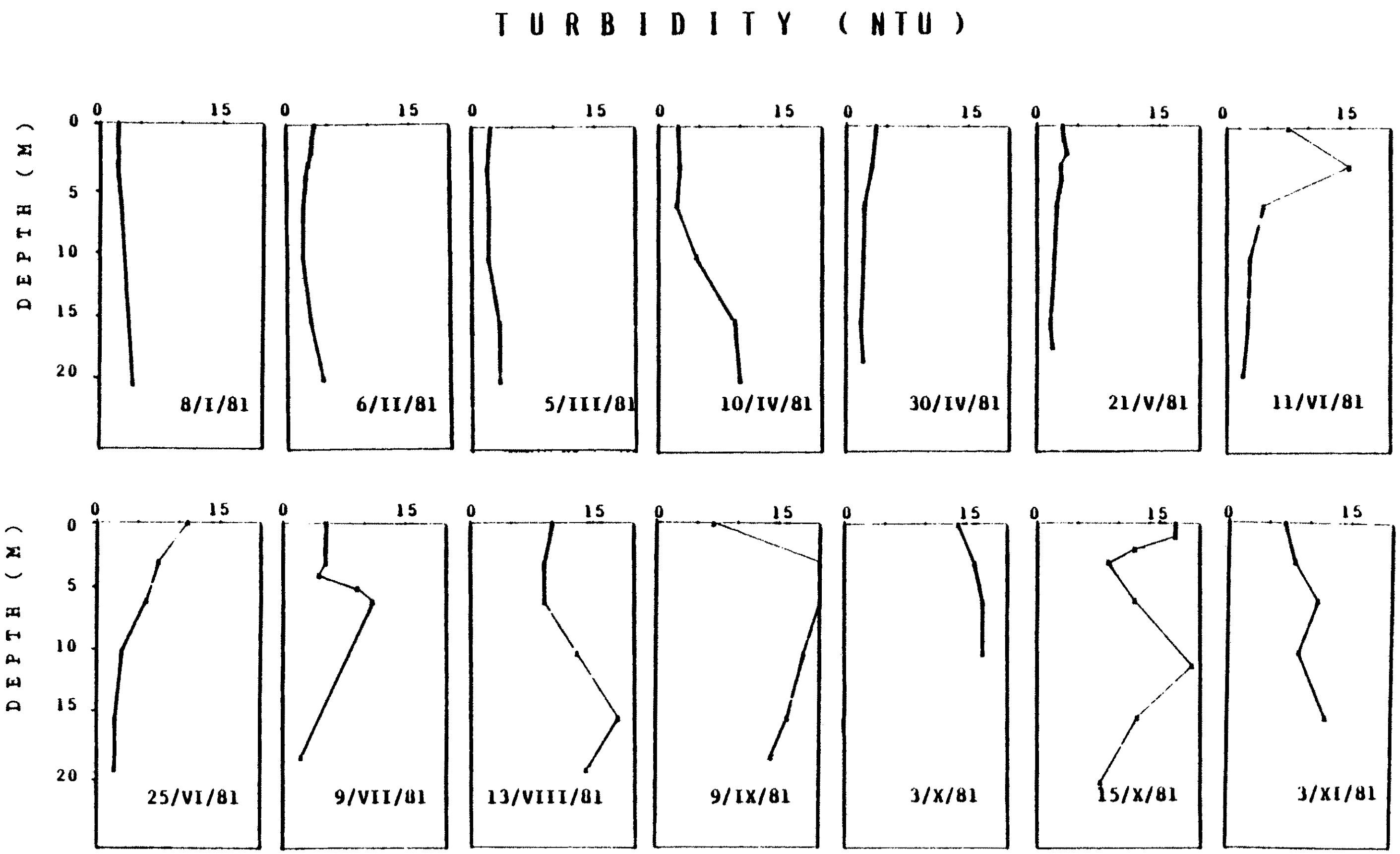


Figure 7.13: Turbidity profiles, L. Yure index station.

Figura 7.13: Perfiles de turbidez en la estación índice del L. Yure.

Plate 7.K. Mass of vegetation debris accumulated at the mouth of Q.Tepemechín, lago Yure.

Foto 7.K. Masa de desechos de plantas acumulada en la boca de la Q. Tepemechín, lago Yure.

(Table 7.3a) demonstrates the importance of the abiogenic component of turbidity in the wet season. Also illustrating the same point is the % AFDW of particulate matter sedimenting out to various depths at a station about 50 m from the dam wall (Table 7.3b). Wet season values were about 20%, and values from the dry season were between 38 and 60% (Knud-Hansen 1983). The difference between the 7 m and 17 m dry season (30 March - 2 April) values of % AFDW presumably resulted from the mineralization of organic matter as it sank through the water column. The lack of any significant change in % AFDW with depth during the wet season further indicated the refractory nature of the sedimenting material at that time.

In order to compare the organic matter content of the bottom sediments with that of particulate matter in the process of sedimentation, samples were collected with an Ekman dredge from a number of stations around the reservoir. Sub-samples of sediment were dried to a constant weight of 104^{o}C, combusted at 550^{o}C and re-weighed. Table 7.4 presents the % weight-loss upon combustion (%AFDW) of the samples. On 7/II/82 a transect along the QdC branch of the reservior was sampled. The station QdC a) was located near the region where the QdC branch opens into the main body of the lake. QdC b) and c) were about 70 m and 15 m, respectively, from the mouth of Q. del Cerro. (The normal sampling station in QdC, the one sampled on 13/I/82, was mid-way between QdC a) and b)).

The results in Table 7.4 show that the sediments of the QdC branch apparently had a higher organic matter content that those from other areas of the reservoir. Within the QdC branch, % AFDW was least nearest the main body of the lake and highest near the inflowing stream. The reason(s) for this gradient, and the overall higher % AFDW of sediments in QdC than in the rest of the lake is (are) not clear, but may reflect a greater input of leaf litter from Q. del Cerro, relative to other streams, and/or different degrees of vegetation clearance in the reservoir basin before inundation occurred.

Table 7.3 a: Percent ash-free dry weight of suspended solids in the canal outflow from L. Yure.

Tabla 7.3 a: Porcentaje del peso seco libre de ceniza de los sólidos suspendidos en el canal del L. Yure.

Period	Mean % (± 1 standard deviation)	N
January - April	59 (± 30)	11
June - September	30 (± 11)	11

Table 7.3 b: Percent ash-free dry weight of material sedimenting out of the water column in L. Yure.

Tabla 7.3 b: Porcentaje del peso seco libre de ceniza del material sedimentándose desde la columna de agua en L. Yure.

Period	Depth of Sample Collection (m)	% AFDW
5-8/VIII/1981	2	21
	7	18
	12	18
	17	18
15-24/VIII/1981	7	20
29/VIII - 1/IX/1981	7	24
	17	18
30/III - 2/IV/1982	7	60
	17	38

Table 7.4: Percent ash-free dry weight of bottom sediments at various stations in L. Yure (see text for description of QdC stations).

Tabla 7.4: Porcentaje de peso seco libre de ceniza de los sedimentos del fondo en varias estaciones en L. Yure (ver texto para la descripción de las estacciones en QdC).

Date of Sample Collection	Station	% AFDW (± standard deviation)	N
13/I/1982	Index	9.6 (± 0.7)	5
	QSN	12.1 (± 0.4)	6
	QdC	19.1 (± 0.5)	6
	QT	12.7 (± 0.5)	6
7/II/1982	QdC a)	14.9 (± 0.6)	4
	QdC b)	22.2 (± 2.3)	4
	QdC c)	22.2 (± 3.2)	4

7.3.4 Conductivity

Conductivity data collected at the index station are presented in Appendix 10. Epilimnetic values usually ranged between 45 and 55 µmho/cm and were similar to those of Q. del Cerro and Q. Sin Nombre, but lower than those of Q. Tepemechín. (This reflects the disproportionate influence of the two former rivers on index station water quality.) Conductivity gradually increased with depth, especially in the lower part of the hypolimnion, to reach values often greater than 65 µmho/cm. This resulted from mineralization of sedimenting organic matter and the release of dissolved material, especially Ca^{++} and HCO_3^- ions, from the sediments when the sediment/water interface became anoxic (see section 7.4.1 and 7.4.2).

7.4 WATER CHEMISTRY

7.4.1 Alkalinity, pH

The alkalinity and pH of surface (0-3 m) and bottom (1 m above sediments) water for selected dates in 1980-1982 are given in Table 7.5. There was generally little variation in surface alkalinities, even during periods of high primary production when the concentration of bicarbonate might be expected to have been reduced through photosynthetic uptake. However, between late-June and October 1981, surface alkalinities decreased to about 7 mg/l $CaCO_3$. There was a corresponding decrease in the alkalinity of the inflowing streams at this time, a trend which had been previously seen (although to a lesser degree) in 1980 (Fig. 6.4, Table A2.16-18). Although the alkalinity of river water usually decreases in the wet season (section 6.2.5), and the L. Yure tributaries obviously had a direct, short-lag influence on reservoir water quality, methodological inaccuracy, although unlikely, cannot be totally ruled out as an

Table 7.5: Alkalinity and pH of surface and bottom water at the L. Yure index station.

Tabla 7.5: Alcalinidad y pH del agua superficial y profunda de la estación índice del L. Yure.

Date	Depth*	pH	Alkalinity (mg/ℓ $CaCO_3$)
1980			
11-I	E	6.8	15
	H	7.6	13
14-II	E	7.2	14.8
	H	7.1	13.7
13-III	E	7.5	15.2
	H	7.8	17.0
24-IV	E	7.6	18.1
	H	6.8	15.5
29-V	E	8.1	--
	H	7.6	--
26-VI	E	8.1	13.0
	H	7.9	23.6
16-VII	E	8.1	13.5
	H	6.3	25.6
7-VIII	E	7.6	12.0
	H	6.5	24.0
18-IX	E	6.9	12.7
	H	6.3	15.1
9-X	E	7.0	10.9
	H	6.4	13.2
30-X	E	6.8	12.0
	H	6.2	12.7
20-XI	E	6.9	13.3
	H	6.4	11.3
10-XII	E	6.7	13.0
	H	6.7	11.5
1981			
8-I	E	6.7	12.9
	H	6.1	11.9
22-I	E	7.2	13.8
	H	6.4	11.0
6-II	E	7.9	11.3
	H	6.2	5.9
23-II	E	7.3	11.0
	H	6.3	10.3
5-III	E	7.4	10.7
	H	6.0	8.0
19-III	E	7.6	11.2
	H	6.9	9.8
10-IV	E	8.4	15.1
	H	5.8	19.0
30-IV	E	8.5	13.3
	H	5.8	14.0
21-V	E	7.8	15.3
	H	5.9	15.7
11-VI	E	7.1	11.4
	H	--	14.5
25-VI	E	6.8	7.2
	H	5.8	--
9-VII	E	7.1	5.0
	H	6.1	9.3
28-VII	E	6.9	9.2
	H	5.8	21.3
13-VIII	E	6.8	7.4
	H	5.6	--
9-IX	E	7.2	8.5
	H	5.7	13
3-X	E	6.7	9.9
	H	--	27.5
15-X	E	7.0	5.7
	H	--	5.5
3-XI	E	7.7	14.7
	H	6.8	25.1
12-XI	E	7.0	13.6
	H	6.1	24.8
3-XII	E	7.4	14.2
	H	--	24.1
1982			
12-I	E	7.8	13.9
	H	7.1	7.0
23-II	E	7.4	14.1
	H	--	10.0
18-III	E	6.5	13.0
	H	--	10.5
29-IV	E	7.6	18.1
	H	--	15.0
27-V	E	6.5	14.7
	H	--	19.4
22-VI	E	6.4	11.5
	H	6.0	20.0
20-VII	E	6.5	13.1
	H	6.0	21.8
18-VIII	E	6.8	10.8
	H	6.5	17.0
28-IX	E	6.9	12.1
	H	6.2	22.0
12-XI	E	6.7	13.3
	H	--	21.0
22-XII	E	7.0	13.2
	H	--	11.0

* E = 0 - 3 meters
H = 1 meter above bottom

explanation for this period of lower alkalinities.

The alkalinity of hypolimnetic water was about the same as, or lower than that of, epilimnetic water between January and March. Under stratified conditions, however, hypolimnetic alkalinities began to increase and from June/July they were approximately twice surface values. Increased alkalinity in anoxic hypolimnia usually results from microbial degradation of organic matter sinking from surface waters and from the release of bicarbonates from the sediments (Wetzel 1983). Uniform alkalinities through the water column were reinstated during full circulation in December/January.

pH decreased in the hypolimnion during periods of oxygen depletion, again a result of the decompositional processes occurring there. Epilimnetic pH ranged from 6.4 to 8.5. Highest values tended to occur during April-June (in 1980 and 1981, at least), coinciding with, and probably resulting from, the periods of higher algal primary production, when photosynthetic activity reduced concentrations of dissolved CO_2.

7.4.2 <u>Oxygen</u>

The oxygen regime of a lake has a major influence on both the biota and nutrient dynamics. The extent of the oxygenated zone determines the proportion of the lake's volume which can be utilized by most zooplankton, benthic invertebrate and fish species. The influence of hypolimnetic oxygen concentrations on nutrient levels (and, in turn, on the primary producers) will be further discussed in the following sections. The present section describes seasonal variation in oxygen concentrations at the L. Yure index station. Section 7.4.9 briefly discusses some of the synoptic oxygen data.

Seasonal variation in oxygen concentrations through the water column is primarily dependent on the lake's thermal regime and thus the degree of mixing. Oxygen levels are also influenced by rates of photosynthesis and the relative depths of the euphotic and mixed zones (see section 9). The amount of organic matter that is (a) produced within the lake (autochthonous production), (b) already present in a newly-flooded reservoir basin, and (c) transported into the lake from the watershed (allochthonous production, i.e. leaf litter, etc.) is a further factor influencing oxygen concentrations, since oxygen is used in its decomposition.

All measurements of dissolved oxygen taken at the index station are recorded in Appendix 10. Fig. 7.7 presents a 1-year series of profiles to illustrate the influence of the thermal regime on oxygen concentrations. In this figure, data are presented as % saturation (since concentration at 100% saturation varies inversely with temperature). The entire 3-year data record is summarized in Fig. 7.14 as a composite depth-time graph. This figure should be interpreted in an analogous way to that described for temperature (section 7.3.1).

It should be noted that the lowest concentrations recorded by the oxygen meter used in this study were often 0.2-0.4 mg/l. These concentrations should probably be read as 0.0 mg/l. In Fig. 7.14, the 0 mg/l isopleth has been omitted because of the problem of meter inaccuracy. However, the zone below the 1 mg/l isopleth can be taken as a reasonably accurate representation of the extent of anoxia since lowest meter readings were usually reached at depths just below those at which 1 mg/l O_2 was recorded.

When the lake was mixing to the bottom, in December and/or January, oxygen concentrations were >60% of saturation at all depths. After stratification had been established, removing the lower water layers from contact with the atmosphere, hypolimnetic oxygen concentrations decreased, so that for 8 months of the year (March-October) the lake was anoxic below 7-10 m. The depth of the oxygenated zone varied during the wet season as storms influenced the position of the thermocline. However, only at the end of the year did water below 10 m

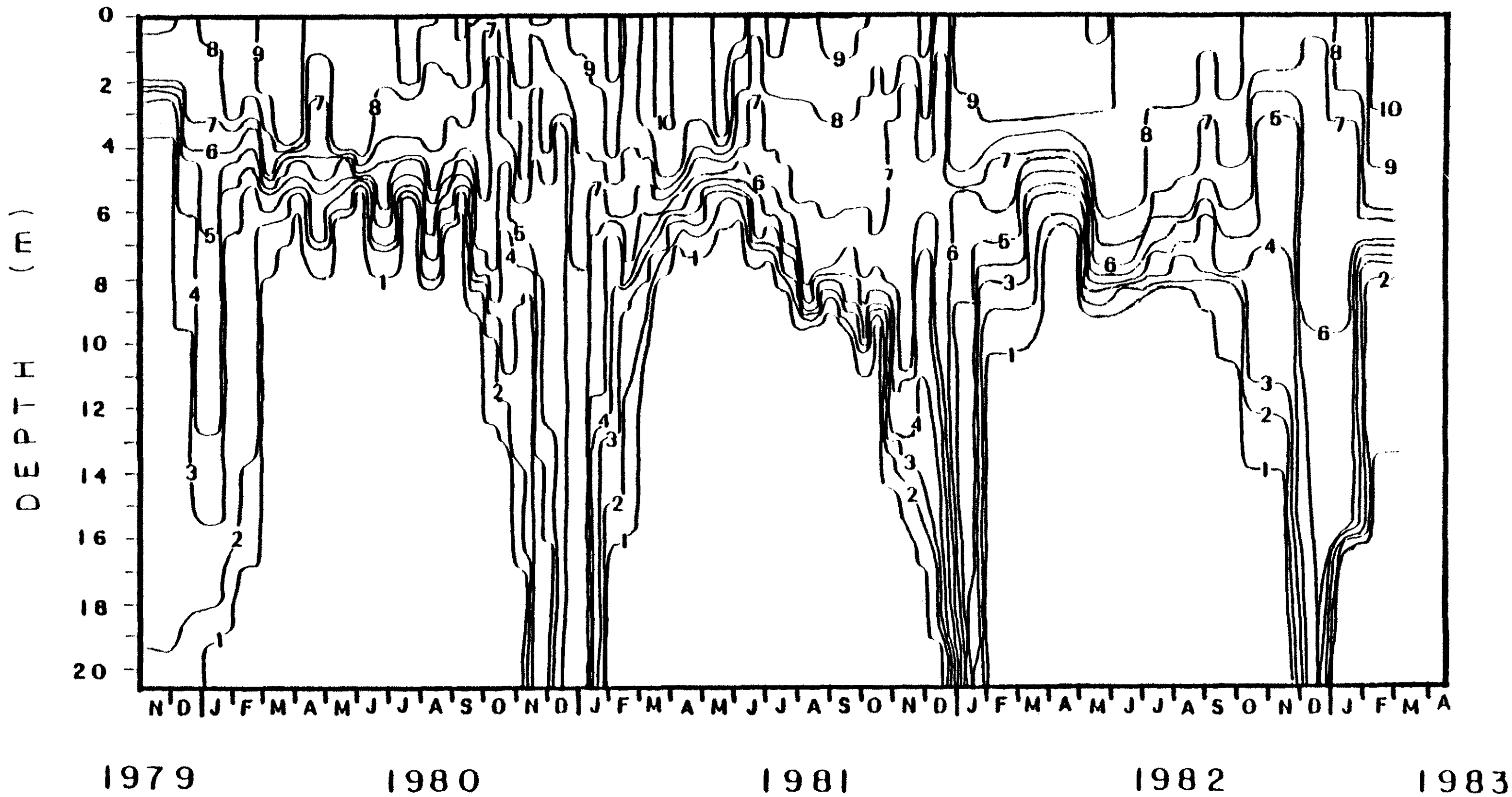


Figure 7.14: Depth-time diagram of oxygen isopleths, L. Yure (mg/l).

Figura 7.14: Diagrama profundidad-tiempo de cotas de oxígeno, L.Yure (mg/l).

become oxygenated.

The depth of the euphotic zone was usually about the same as, or less than, the depth of the mixed zone (Fig. 9.1). Significant rates of photosynthesis therefore did not occur in the hypolimnion, further contributing to the decrease in oxygen concentrations below the thermocline.

Surface water was often supersaturated with oxygen, especially at times when rates of primary production were high. Occasionally, metalimnetic oxygen maxima were observed (i.e. highest concentrations at an intermediate depth). For example, on 10/IV/81 the % saturation was higher at 1 m than at the surface. This was probably a result of the higher photosynthetic rate at 1 m on that date (Table 7.9, Fig. 7.22). Conversely, on some dates there was a metalimnetic oxygen minimum, for example at 3 m on 3/X/81. Metalimnetic oxygen minima are often caused by increased concentrations of decomposing organic matter or higher zooplankton densities in a water stratum. These lead to increased oxygen consumption rates at that depth and thus lower oxygen concentrations.

The seasonal pattern of oxygen depletion was similar in each of the three years of the study. However, circulation during December 1979 and January 1980 apparently was not sufficient to fully re-oxygenate hypolimnetic water, since concentrations below 16 m did not exceed 3 mg/l. This may have been because the lake only mixed fully over a short period of time and/or because the oxygen demand by hypolimnetic water was higher at that time than in subsequent years. Biochemical oxygen demand (BOD) was not measured on a routine basis during the study, so it is not possible to compare the oxygen demand of hypolimnetic water over the three year period. The 5-day BOD of deep water during the period May-July 1982, however, was about 2.8 mg/l, which was approximately 3x surface values.

A probable example of the influence of turbidity currents on hypolimnetic oxygen concentrations was observed on two occasions in L. Yure. On 7/VIII/80, the hypolimnion of QdC was anoxic below 11 m, except for the stratum between 14 and 15 m where there was about 1 mg/l oxygen. On 28/VIII/80, in the QT branch of the reservoir, oxygen concentrations increased from 0.3 mg/l at 13 m to 2.3 mg/l at 15 m (Fig. 7.20).

On both these occasions, high rainfall had been recorded two days previously (c.f. Fig. 7.3) and the lake was above spillway level on 28/VIII/80. It would appear probable (though cannot be proved since the tributaries were not sampled on the days of high rainfall) that the temperature and suspended sediment load of the inflowing streams resulted in an underflow of stream water along the bottom of the lake. High, storm-induced, discharge rates were presumably sufficient to cause the underflowing stream water to maintain its identity (e.g. a non-zero concentration of dissolved oxygen) as far into the lake as the QdC and QT sampling stations.

Further evidence for underflow extending into the main body of the lake at this time comes from temperature profiles at both QT and the index station (Appendix 10, Fig. A10.1). The bottom few meters of the water column were warmer than the overlying water at both stations on 28/VIII/80 and 3/IX/80. Note, however, that the underflowing water had lost its dissolved oxygen by the time it reached the index station. Increased turbidity of this bottom water was indicated by its very high iron concentrations (Table 7.6).

7.4.2. Phosphorus

Because of its central role in influencing the productivity of many aquatic systems, a considerable number of investigations have been carried out on the dynamics of phosphorus in reservoirs and lakes. While it is not the intention to summarize here present knowledge on phosphorus dynamics, a brief description is given of the major factors influencing lake phosphorus concentrations. Processes influencing phosphorus dynamics in terrestrial ecosystems and rivers

Table 7.6: Nutrient concentrations at the L. Yure index stations, 1979-1982.

Tabla 7.6: Concentraciones de nutrientes en la estación índice del L. Yure, 1979-1982.

Table 7.6

Date	Depth (m)	Total-P (μg/l)	PO_4-P (μg/l)	NO_3-N (μg/l)	NH_4-N (μg/l)	SiO_2 (mg/l)	Fe (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)
7/XI/79	0	16	-	-	7	9.4	.07	0.4	1.6	3.7	2.4
	17	116	-	-	92	3.2	1.92	1.1	0.3	3.4	3.6
29/XI/79	0	10	6	50	9	6.4	0.10	0.5	2.1	3.4	2.2
	20	27	12	99	149	1.0	0.65	0.4	0.3	3.4	3.2
13/XII/79	0	9	12	97	2	8.6	0.11	0.4	1.3	3.3	2.1
	23	6	20	127	67	0.8	0.27	0.2	0.8	3.4	2.4
11/I/80	0-5	8	8	84	136	5.0	0.14	0.2	0.7	3.4	2.3
	18	10	12	91	152	2.0	0.21	0.2	0.6	3.3	2.2
30/I/80	0-5	10	7	122	0	11.0	0.13	0.3	1.1	3.8	2.4
	17	5	10	200	20	3.2	0.30	0.3	1.0	3.6	2.2
14/II/80	0-5	20	9	58	4	8.4	0.07	0.3	1.3	3.8	2.4
	20	47	20	90	52	2.6	1.04	0.4	0.6	4.3	2.8
28/II/80	0-9	12	12	36	0	6.8	0.08	0.3	1.5	4.2	2.4
	19	12	12	70	30	2.2	0.44	0.3	1.6	4.2	2.4
13/III/80	0-5	17	12	30	4	13.4	0.08	0.3	1.7	3.8	2.4
	18.5	26	9	84	60	5.6	0.36	0.4	1.6	3.6	2.4
26/III/80	0-5	21	2	90	4	12.8	0.09	0.4	2.0	4.0	2.5
	18.5	16	1	104	124	4.8	0.42	0.4	2.0	4.0	2.6
24/IV/80	0-5	14	10	66	4	13.0	0.06	0.3	1.8	3.8	2.6
	16.5	9	6	80	150	11.5	2.37	0.4	2.2	3.5	2.4
15/V/80	0-5	16	2	66	0	11.8	0.09	0.3	1.4	3.9	2.4
	17	9	4	57	196	3.4	1.25	0.4	2.0	3.4	2.2
29/V/80	0-3	18	7	21	4	13.4	0.09	0.4	1.6	4.0	2.4
	17	13	10	42	321	2.7	0.68	0.4	1.8	3.4	2.3
26/VI/80	0-4	15	11	194	10	-	0.09	0.3	1.2	3.2	2.4
	19	11	7	138	372	-	1.04	0.4	2.2	3.6	2.4
16/VII/80	0-5	17	8	77	0	12.4	0.05	0.3	1.4	3.6	2.4
	20	14	10	59	335	12.4	0.85	0.4	2.4	3.7	2.4
28/VIII/80	0-3	17	6	159	12	8.3	0.18	-	-	-	-
	18.5	76	2	146	830	2.9	7.70	-	-	-	-
18/IX/80	0-3	10	3	-	22	9.1	0.38	0.4	2.2	3.0	2.2
	19	52	10	-	188	2.3	2.87	1.0	3.0	3.0	2.4
9/X/80	0-2	12	2	-	14	8.2	0.12	0.4	2.6	3.0	2.0
	21	88	8	-	180	1.8	1.17	3.0	3.8	3.0	3.3
30/X/80	0-3	13	4	180	0	9.4	0.30	0.4	2.8	3.4	2.5
	22.5	80	8	52	152	2.8	2.10	6.0	5.8	3.4	5.2
20/XI/80	0-3	18	6	146	12	9.1	0.51	0.4	2.8	3.3	2.4
	17.5	29	15	210	16	3.7	0.71	0.6	2.4	3.1	2.4
10/XII/80	0-4	8	1	192	16	10.8	0.15	0.4	3.4	3.8	2.4
	18.5	6	1	232	38	7.3	0.18	0.4	2.5	3.7	2.4
8/I/81	0-12	15	6	169	23	10.7	0.08	0.3	2.4	3.4	2.4
	20	19	8	203	32	4.9	0.13	0.3	2.3	3.4	2.4
22/I/81	0	26	5	140	22	11.6	0.13	0.3	2.6	3.4	2.0
	3	18	4	150	23	12.4	0.10	0.3	2.8	3.8	2.4
	6	17	5	166	19	10.0	0.07	0.3	2.2	3.4	2.1
	10	14	3	186	23	6.3	0.09	0.3	2.0	3.4	2.1
	15.5	12	2	174	40	7.6	0.13	0.3	2.1	3.6	2.2

Table 7.6 (cont.)

Date	Depth (m)	Total-P (μg/l)	PO_4-P (μg/l)	NO_3-N (μg/l)	NH_4-N (μg/l)	SiO_2 (mg/l)	Fe (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)
6/II/81	0	24	4	46	26	9.0	0.04	-	-	-	-
	3	31	3	57	20	9.8	0.11	-	-	-	-
	6	23	4	66	22	10.5	0.11	-	-	-	-
	10	12	2	81	39	2.9	0.16	-	-	-	-
	15	17	1	122	44	3.4	0.14	-	-	-	-
	19.5	11	10	61	46	3.2	0.20	-	-	-	-
23/II/81	0	18	3	64	22	3.6	0.05	0.4	3.0	3.8	2.4
	3	11	6	108	18	12.4	0.04	0.3	2.3	3.8	2.7
	6	21	4	182	22	9.3	0.05	0.3	2.0	3.3	2.6
	10	10	6	47	62	5.5	0.08	0.3	2.6	3.5	2.2
	15	14	4	76	76	7.3	0.13	0.4	2.6	3.5	2.3
	21.5	11	6	66	80	4.8	0.24	0.4	2.6	3.6	2.2
5/III/81	0	13	2	12	22	9.4	0.10	-	-	-	-
	3	10	2	46	30	9.2	0.07	-	-	-	-
	6	12	2	100	27	8.4	0.08	-	-	-	-
	10	7	2	92	53	4.6	0.11	-	-	-	-
	15	6	1	60	68	3.6	0.38	-	-	-	-
	19.5	6	1	61	62	3.8	0.52	-	-	-	-
19/III/81	0-6	6	3	116	33	12.3	0.06	0.4	2.6	3.8	2.6
	16.5	8	6	69	129	8.8	0.39	0.4	3.0	3.7	2.4
10/IV/81	0	14	6	12	26	13.8	0.07	-	-	-	-
	3	17	5	67	33	13.4	0.06	-	-	-	-
	6	12	6	70	23	9.1	0.06	-	-	-	-
	10	7	6	46	126	8.0	0.23	-	-	-	-
	15	8	6	24	158	7.1	0.46	-	-	-	-
	19	38	5	28	182	7.8	0.99	-	-	-	-
30/IV/81	0	15	4	36	22	10.8	0.09	0.4	4.1	4.0	2.5
	3	13	2	102	26	10.8	0.07	0.3	2.7	4.0	2.6
	6	8	3	168	26	6.4	0.08	0.3	2.6	3.4	2.2
	10	5	3	9	164	4.8	0.33	0.4	3.3	3.6	2.4
	15	5	5	16	262	3.4	0.83	0.5	3.8	3.7	2.4
	18	20	6	13	286	3.4	0.93	0.5	3.8	3.6	2.4
21/V/81	0	29	4	10	19	15.2	0.07	0.4	3.5	4.4	2.6
	3	40	1	18	19	15.2	0.07	0.4	3.2	4.4	2.6
	6	38	3	34	20	11.2	0.05	0.4	3.3	3.7	2.4
	10	22	12	10	188	4.3	0.62	0.4	3.8	3.7	2.3
	15	24	2	12	210	3.7	1.09	0.4	2.2	3.6	2.3
	17	74	4	14	260	4.3	1.16	0.5	5.2	3.8	2.6
11/VI/81	0	13	1	45	30	10.6	0.09	0.4	3.3	3.9	2.7
	3	26	4	56	22	6.9	0.24	0.4	2.8	3.6	2.9
	6	16	4	56	38	4.2	0.10	0.3	2.8	3.8	2.6
	10	8	4	10	206	2.4	0.56	0.4	3.8	3.6	2.4
	15	4	4	18	268	2.3	1.06	0.5	4.1	3.8	2.4
	19	12	6	22	312	2.3	1.24	0.5	4.4	3.9	2.4
25/VI/81	0	22	3	115	21	9.2	0.17	0.3	2.6	3.4	2.6
	3	22	3	176	17	7.3	0.10	0.3	2.6	3.4	2.6
	6	17	4	108	24	5.5	0.09	0.4	3.1	3.5	2.4
	10	16	4	10	236	2.6	0.50	0.4	3.9	3.6	2.5
	15	16	5	18	310	2.9	0.96	0.5	4.4	3.8	2.5
	19	49	8	20	355	3.2	1.13	0.5	4.4	3.8	2.4
9/VII/81	0-4	56	5	116	7	10.6	0.07	-	-	-	-
	18	61	8	18	435	3.8	1.19	0.6	4.6	4.2	3.0

Table 7.6 (cont.)

Date	Depth (m)	Total-P (μg/l)	PO_4-P (μg/l)	NO_3-N (μg/l)	NH_4-N (μg/l)	SiO_2 (mg/l)	Fe (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)
28/VII/81	0-3	34	2	80	26	8.7	1.15	0.4	2.8	3.9	2.9
	18	36	3	110	526	3.4	1.21	0.7	5.2	4.4	3.2
13/VIII/81	0	70	4	81	-	10.0	0.15	-	-	-	-
	3	85	3	97	-	8.2	0.10	-	-	-	-
	6	65	2	88	-	8.2	0.10	-	-	-	-
	10	67	2	102	-	5.0	0.14	-	-	-	-
	15	64	3	104	-	4.2	1.03	-	-	-	-
	19	93	6	108	-	3.4	1.23	-	-	-	-
9/IX/81	0	26	5	92	22	6.0	0.10	-	-	-	-
	3	35	7	126	26	5.4	0.27	-	-	-	-
	6	42	6	112	41	5.7	0.28	-	-	-	-
	10	64	6	94	63	3.5	0.24	-	-	-	-
	15	22	6	10	539	3.4	1.54	-	-	-	-
	20	54	10	24	560	2.9	1.41	-	-	-	-
29/IX/81	0-4	12	6	180	12	6.0	0.03	-	-	-	-
	19	20	10	22	572	1.8	0.56	-	-	-	-
3/X/81	0	15	7	-	18	5.4	0.14	-	-	-	-
	3	19	7	68	21	2.1	0.11	-	-	-	-
	6	14	8	84	22	2.2	0.09	-	-	-	-
	10	16	6	50	40	1.4	0.14	-	-	-	-
	15	23	5	11	352	2.6	0.57	-	-	-	-
	21	18	7	9	574	1.2	1.35	-	-	-	-
15/X/81	0	20	4	106	16	4.7	0.12	-	-	-	-
	3	14	4	138	15	5.3	0.09	-	-	-	-
	6	22	4	102	16	3.2	0.14	-	-	-	-
	10	21	3	100	51	3.4	0.13	-	-	-	-
	15	51	10	26	298	2.0	0.61	-	-	-	-
	20	44	2	32	555	2.6	0.61	-	-	-	-
3/XI/81	0	12	6	68	16	9.8	0.06	-	-	-	-
	3	12	7	88	17	7.0	0.09	-	-	-	-
	6	14	6	76	22	5.7	0.05	-	-	-	-
	10	11	5	84	32	7.2	0.06	-	-	-	-
	15	12	7	82	114	3.8	0.05	-	-	-	-
	19	87	6	38	280	3.4	0.45	-	-	-	-
12/XI/81	0	11	4	78	16	7.0	0.06	-	-	-	-
	3	9	9	82	7	4.0	0.05	-	-	-	-
	6	10	5	146	16	4.2	0.06	-	-	-	-
	10	10	4	126	22	4.4	0.05	-	-	-	-
	15	14	6	64	90	4.0	0.08	-	-	-	-
	21	55	8	34	620	2.9	0.57	-	-	-	-
3/XII/81	0-3	12	2	26	11	7.0	0.01	-	-	-	-
	20	40	8	47	123	2.3	0.30	-	-	-	-
12/I/82	0	48	4	87	8	6.0	0.07	-	-	-	-
	3	32	5	147	3	6.6	0.06	-	-	-	-
	6	30	6	207	5	1.2	0.04	-	-	-	-
	9	19	6	209	10	3.5	0.02	-	-	-	-
	12	10	6	228	10	1.5	0.08	-	-	-	-
	15	12	6	572	8	1.2	0.09	-	-	-	-
	19	11	6	561	6	1.3	0.18	-	-	-	-
23/II/82	0	26	2	74	58	12.4	0.08	-	-	-	-
	3	30	1	108	54	12.6	0.10	-	-	-	-
	6	23	4	124	50	11.0	0.11	-	-	-	-

Table 7.6 (cont.)

Date	Depth (m)	Total-P (µg/l)	PO_4-P (µg/l)	NO_3-N (µg/l)	NH_4-N (µg/l)	SiO_2 (mg/l)	Fe (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)
23/II/82	10	24	2	152	92	8.0	0.11	-	-	-	-
	15	24	3	160	126	6.5	0.37	-	-	-	-
	18	22	4	142	150	5.1	0.42	-	-	-	-
18/III/82	0	17	2	137	40	11.3	0.08	-	-	-	-
	3	19	5	146	44	11.6	0.07	-	-	-	-
	6	16	6	161	47	7.7	0.06	-	-	-	-
	10	18	12	223	82	4.6	0.18	-	-	-	-
	15	14	4	168	154	3.6	0.30	-	-	-	-
	18	35	-	101	191	4.5	0.59	-	-	-	-
29/IV/82	0	9	2	18	43	12.9	0.10	-	-	-	-
	3	15	6	24	40	14.0	0.09	-	-	-	-
	6	16	5	29	36	13.0	0.10	-	-	-	-
	10	15	8	98	87	5.4	0.23	-	-	-	-
	15	12	7	90	257	5.4	0.55	-	-	-	-
	17.5	52	7	102	272	1.4	0.52	-	-	-	-
27/V/82	0	52	4	54	40	9.4	0.13	-	-	-	-
	3	50	2	191	46	10.2	0.09	-	-	-	-
	6	71	2	164	42	9.7	0.15	-	-	-	-
	10	68	2	102	94	7.8	0.14	-	-	-	-
	15	54	2	90	342	6.7	0.67	-	-	-	-
	17.5	69	4	98	396	7.2	0.20	-	-	-	-
22/VI/82	0	10	4	140	28	3.9	0.12	-	-	-	-
	3	12	6	230	39	3.6	0.13	-	-	-	-
	6	18	4	202	40	8.4	0.17	-	-	-	-
	10	16	6	109	-	6.5	0.11	-	-	-	-
	15	15	9	51	420	3.7	0.79	-	-	-	-
	19	20	10	57	460	2.0	1.15	-	-	-	-
20/VII/82	0	6	5	92	20	11.0	0.08	-	-	-	-
	3	6	6	106	24	12.0	0.07	-	-	-	-
	6	8	6	100	40	11.2	0.07	-	-	-	-
	10	12	6	56	176	8.5	0.09	-	-	-	-
	15	20	10	46	512	4.6	1.30	-	-	-	-
	18	70	20	59	554	5.6	1.73	-	-	-	-
18/VIII/82	0	9	3	194	8	10.6	0.12	-	-	-	-
	3	20	7	139	24	10.0	0.19	-	-	-	-
	6	10	8	98	43	9.6	0.11	-	-	-	-
	10	11	6	90	134	7.4	0.16	-	-	-	-
	15	44	36	64	619	5.0	1.44	-	-	-	-
	18	35	26	65	618	5.8	1.66	-	-	-	-
28/IX/82	0	16	6	181	6	11.4	0.14	-	-	-	-
	3	20	6	206	10	11.6	0.12	-	-	-	-
	6	17	6	161	24	10.4	0.14	-	-	-	-
	10	12	6	72	107	8.5	0.17	-	-	-	-
	15	54	23	58	634	7.4	1.62	-	-	-	-
	18	64	28	70	870	7.6	2.14	-	-	-	-
12/XI/82	0	8	5	161	24	3.7	0.15	-	-	-	-
	3	10	5	178	50	4.6	0.12	-	-	-	-
	6	7	5	156	68	3.0	0.20	-	-	-	-
	10	8	4	175	91	2.8	0.24	-	-	-	-
	15	15	5	151	110	2.6	0.58	-	-	-	-
	19.5	22	6	24	118	2.4	2.03	-	-	-	-

have already been summarized in Section 6.2.7.

Phosphorus exists in several forms in fresh waters, but plants take it up primarily as PO_4-P. Other, more complex, forms of phosphorus can be utilized by some phytoplankton species, especially when this nutrient is limiting (Vincent 1981).

Since phosphorus concentrations are quite often low relative to the demand by phytoplankton, and since PO_4-P is rapidly re-cycled between cells and the surrounding water, levels of PO_4-P in epilimnetic water are often very low. This is so even when phosphorus loading to the system is high (e.g. after a storm event), since phytoplankton are able to take up PO_4-P in quantities greater than are needed at that time. This phenomenon has been termed luxury consumption and results in the storage of excess PO_4-P within algal cells.

An additional process which results in reduced epilimnetic PO_4-P concentrations is the sedimentation of phosphorus-containing organic matter and of inorganic particles (especially clays and ferric hydroxides) onto which PO_4-P is adsorbed (c.f. transport of PO_4-P by suspended material in rivers, sections 6.2.6 and 6.2.7).

The other major factor influencing lake phosphorus concentrations is the amount of oxygen present in water near the sediment interface. Under oxidized conditions, iron is present as the ferric form (Fe^{+++}) which is exceedingly insoluble. It therefore precipitates out, usually as Fe PO_4 and thus removing PO_4-P from solution. When conditions at the sediment water-interface become anoxic (specifically, when the redox potential, a measure of reducing conditions, reaches +200 mV), however, ferric iron is reduced to ferrous (Fe^{++}) which is more soluble. Fe^{++} ions can then move from the sediments into the overlying water, effectively releasing the previously combined or adsorbed PO_4-P into the hypolimnion. Although the oxidized sediment layer is often only a few millimeters thick (microbial metabolism usually ensures anaerobic conditions below this surface layer) it is of crucial importance in determining the phosphorus concentration of the overlying water.

Thus in an anaerobic hypolimnion, phosphorus release from the sediments and from sinking iron-containing particles increases ambient phosphorus concentrations. When the lake mixes, phosphorus-rich hypolimnetic water is re-introduced into the epilimnion where it again becomes available to phytoplankton. The thermal regime of a lake therefore has a very significant influence on the lake's nutrient regime and thence, on its productivity.

This classical explanation of phosphorus dynamics may not represent the major factor influencing phosphorus in all lakes, however. There is evidence that significant amounts of phosphorus can move across the oxic sediment-water interface as a result of disturbance of sediments, either by wind-induced water movement (Lee et al., 1977) or by the activities of invertebrates and benthic-feeding fish (Neame 1977).

Because of the transport of phosphorus to the sediments, either combined in or adsorbed to particulate matter, lake sediments are usually considered to act as a sink (store) for this nutrient. In other words, much of the total phosphorus entering a lake is "trapped" in the sediments. However, rather than (or in addition to) acting as a sink, the sediments may act as a buffer by regulating the amount of phosphorus in the water column (Golterman 1977).

Phosphorus concentrations at the L. Yure index station are given in Table 7.6, and a representative annual series of PO_4-P and total-P profiles is presented in Fig. 7.15. Seasonal fluctuations in phosphorus input to the reservoir from its major tributaries are summarized in Figs. 7.16 and 6.4.

Epilimnetic PO_4-P concentrations (strictly soluble reactive phosphorus; see section 6.2.7) were always low (<10 $\mu g l^{-1}$), even during the wet season when phosphorus loading was high (Fig. 7.16). Comparison of the PO_4-P concentrations

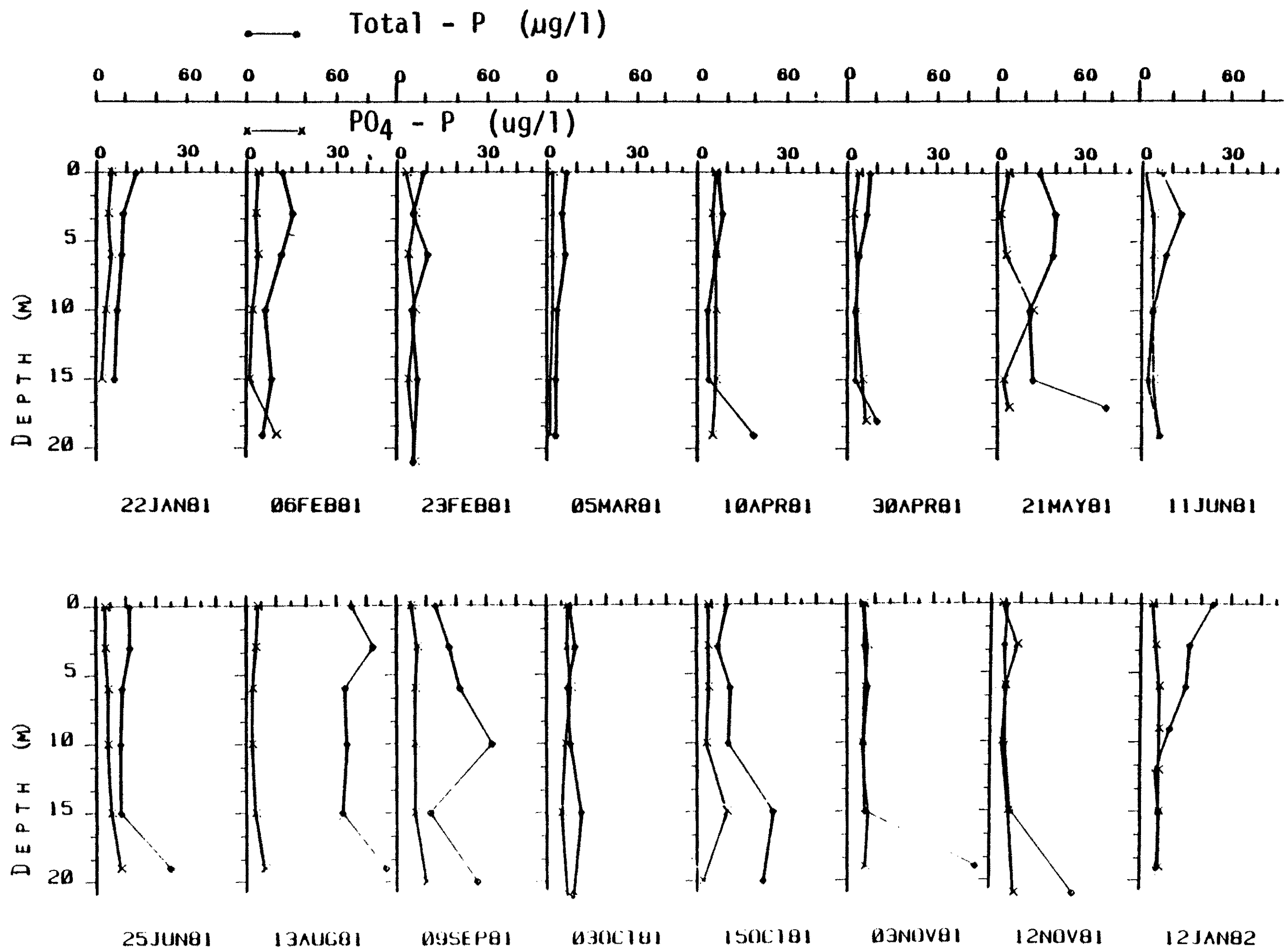


Figure 7.15: Depth profiles of inorganic phosphorus, L. Yure index station.

Figura 7.15: Perfiles de profundidad de fósforo inorgánico en la estación índice del L. Yure.

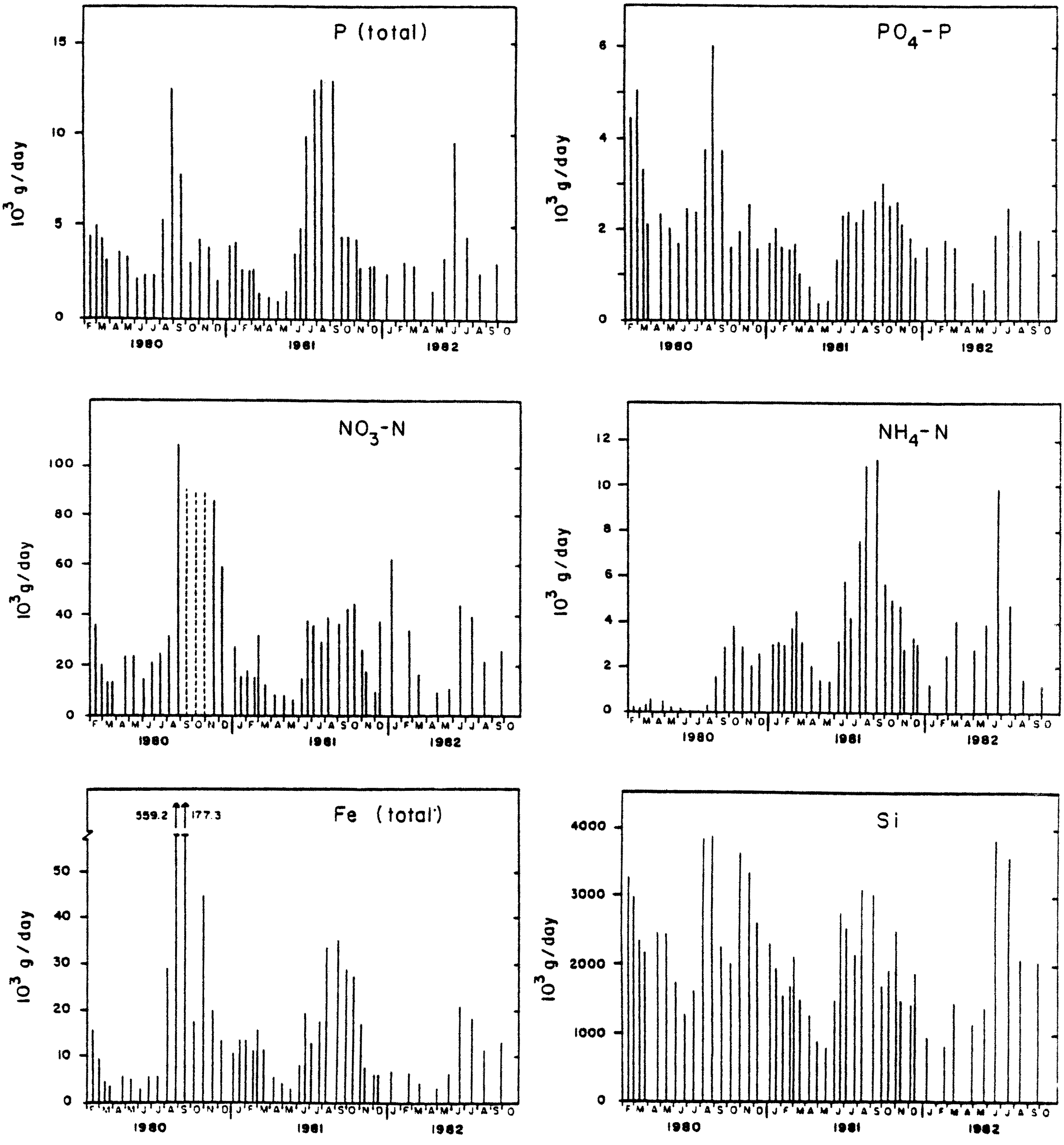


Figure 7.16: Total nutrient loading from the three major tributaries of L. Yure.

Figura 7.16: Cantidad total de nutrientes acareados por los tres principales tributarios del L. Yure.

in water flowing out of L. Yure (via the canal, Fig. 6.4) with those of the inflowing tributaries (Q. del Cerro and Q. Tepemechín), demonstrates the removal of PO_4-P from epilimnetic water, presumably by the algal uptake and sedimentation processes discussed above. (The Yure-Yojoa canal represents an epilimnetic outflow.) A comparison of estimates of seasonal phosphorus input and output for the L. Yure system is deferred to Section 7.4.10.

During periods of complete or nearly complete mixing, PO_4-P concentrations were uniformly low throughout the water column. When the lake was stratified during 1980 and 1981, hypolimnetic PO_4-P concentrations also remained low and thus did not follow the general trend discussed at the beginning of this section. However, in 1982, between July and September, PO_4-P concentrations did increase in the lower part of the hypolimnion, reaching over 30 μg/l (Table 7.6.). This increase is shown in Fig. 7.17. The difference between 1982 and the previous two years is interesting and may have been related to the large increase in primary productivity that was observed in 1982 (Fig. 7.23, section 7.5).

Since the hypolimnion was anoxic during more than nine months in each of the three years of the study, and since hypolimnetic PO_4-P concentrations did not increase under these anoxic conditions during the first two years , it would appear that phosphorus concentrations (at least PO_4-P) in the sediments and in sinking organic matter were not high enough to enrich the overlying water. This situation may have resulted from one or more of the following hypotheses:

1) Phosphorus leached from the (previously burnt) vegetation and soils flooded by the new reservoir was flushed from the system during the first year of its existence.

2) Soils were very poor in phosphorus when first inundated.

3) Rapid recycling within the epilimnion by the plankton community

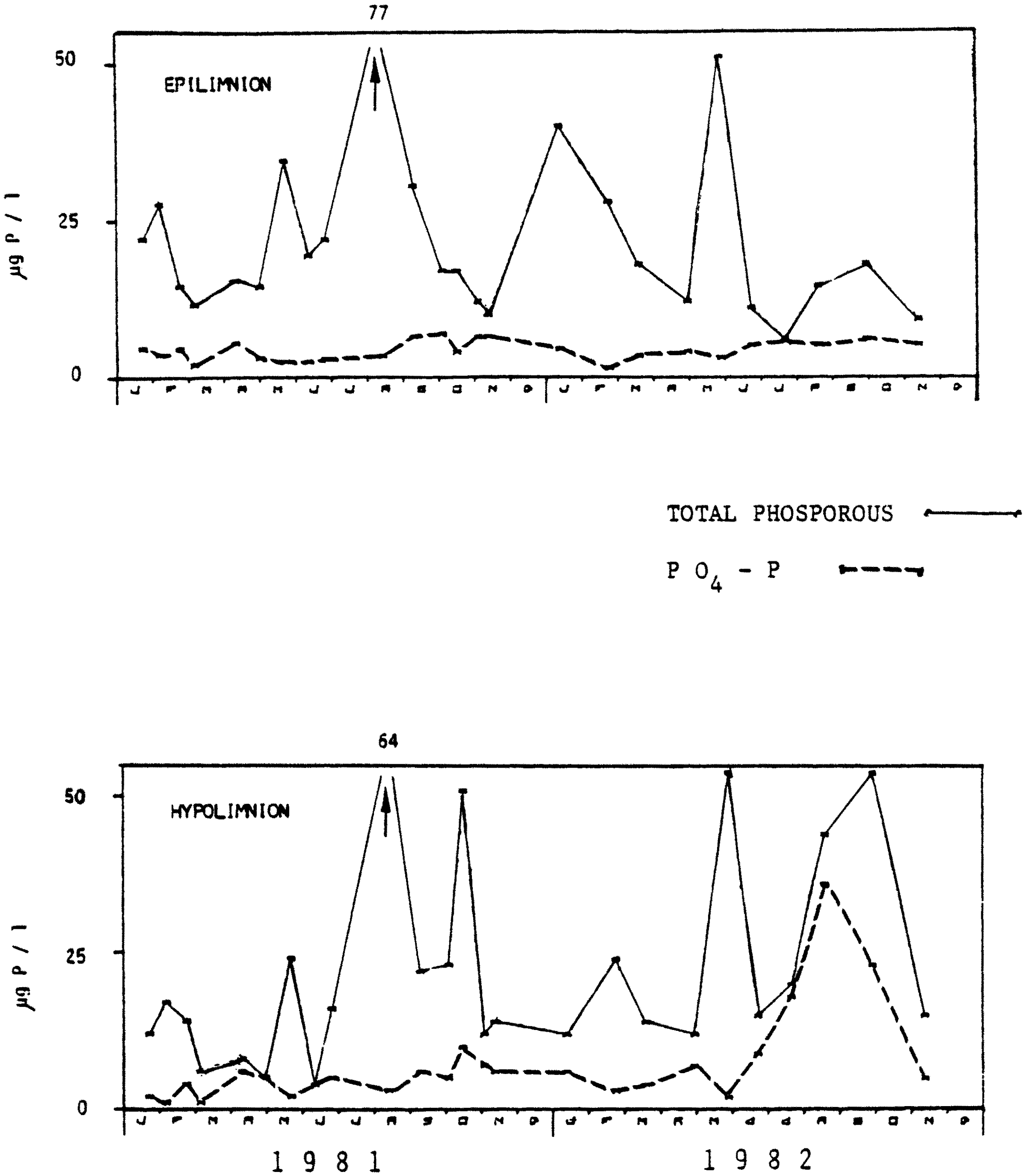


Figure 7.17: Mean epilimnetic and hypolimnetic concencentrations of PO_4 and total-P, L. Yure index station.

Figura 7.17: Concentraciones medias epilimnéticas e hipolimnéticas de PO_4-P y P-Total en la estación índice del L. Yure.

prevented a significant net loss to the sediments of the phosphorus entering the reservoir.

Evidence revealing tight recycling of epilimnetic phosphorus was obtained in August and September 1981 and April 1982, when the sedimentation rate of particulate phosphorus was measured (Knud-Hansen 1983). Rates were low, representing a loss equivalent to 1-6% of epilimnetic phosphorus.

If, as hypothesized above, the sediments of L. Yure were initially too poor in phosphorus to significantly enrich anoxic hypolimnetic water, then the elevated PO_4-P concentrations observed in 1982 may have represented a consequence of the initial stages of phosphorus accumulation in the sediments. In many lakes, sediments act as a sink, or trap, for phosphorus. The high primary productivity observed during January-June 1982 probably significantly increased the quantity of phosphorus-containing organic matter sedimenting to the hypolimnion.

With the present data-base it is not possible to adequately understand phosphorus dynamics in L. Yure. Data from 1983, at least, are required in order to know if the higher hypolimnetic PO_4-P concentrations on the three sampling dates in 1982 represented the beginning of a longer-term trend, or were anomalous. This phenomenon merits much further investigation because of its relation to lake productivity and its importance to the dynamics of the El Cajón reservoir (see Section 9).

PO_4-P usually represented much less than 50% of total phosphorus (TP), a situation characteristic of most lakes and resulting from the rapid uptake/recycling of PO_4-P by phytoplankton. Wet season (May-October) concentrations of TP were very variable, fluctuating primarily in response to storms and the resultant increased loading of inorganic particulate phosphorus (Figs. 7.15 and 7.17). Heavy rain on 12-13/VIII/81 and 8/IX/81 (c.f. Fig. 7.3), for example, resulted in the high TP concentrations observed throughout the water column on 13/VIII/81 and 9/IX/81 respectively. The TP profile for 15/X/81 probably represents sedimenting particulate material which entered the lake during storms on 11/X/81. Note that high TP concentrations in the hypolimnion were not associated with increased PO_4-P concentrations, despite the anoxic conditions. As discussed above, only in July, August and September 1982 were high levels of both forms of phosphorus observed in the hypolimnion.

7.4.4 Nitrogen

Nitrogen, like phosphorus, has been the subject of a very large number of limnological studies because of 1) its importance as the principal factor limiting primary productivity in some natural lakes and reservoirs and 2) the various biologically-mediated processes which are involved in the dynamics of this nutrient.

Dissolved inorganic nitrogen is present in freshwaters, primarily as nitrate (NO_3^-) and ammonia (NH_4^+). Concentrations of nitrite (NO_2^-) are generally very low. (Note, however, that the method used in this study for the analysis of nitrate measures [NO_3^- + NO_2^-], so the NO_3-N concentrations presented here properly refer to nitrate + nitrite.) Dissolved organic nitrogen is usually a significant fraction of the total dissolved nitrogen, often more than 50% (Wetzel 1983), and represents compounds released from living and decomposing cells.

No attempt will be made here to summarize the various processes, such as nitrification, denitrification, and nitrogen fixation, which are involved in lake nitrogen dynamics (for details of the nitrogen cycle, see Goldman & Horne 1983). Quantification of these processes in L. Yure was beyond the scope of the present monitoring study. However, a more detailed investigation of them in the future would certainly be advisable for a better understanding of nutrient dynamics and limitation in the El Cajón reservoir.

NH_4-N and NO_3-N concentrations at the L. Yure index station are presented in Table 7.6, and a representative annual series of depth profiles illustrating the seasonal fluctuations in dissolved inorganic nitrogen is seen in Fig. 7.18. These profiles clearly show that there was an inverse relationship between NO_3-N and NH_4-N concentrations. NH_4^+, which is produced from the microbial degradation of nitrogen-containing organic compounds, was always present at low concentrations in the oxygenated water of the epilimnion, presumbaly because of its rapid uptake by phytoplankton and/or its oxidation to NO_3^- (nitrification). At times when the lake was mixing to the bottom (January), NH_4-N levels were low throughout the entire water column. During the period of stratification, NH_4^+ gradually accumulated in the hypolimnion, as organic matter produced in the epilimnion sedimented out and was mineralized by heterotrophic bacteria. Anoxic conditions prevented nitrification (the oxidation of NH_4^+ to NO_3^-) from occurring, leading to the build-up of NH_4^+. This seasonal pattern can be clearly seen in Fig. 7.18. Note that as the thermocline depth increased during October and November, the gradual re-introduction of oxygen to the lower water strata resulted in decreased NH_4-N concentrations. After turnover (mixing to the bottom), NH_4-N levels were uniformly low from surface to bottom.

NO_3-N concentrations tended to increase with depth during periods of deep mixing. This presumably resulted from uptake of NO_3^- by phytoplankton in the surface waters and the release of NO_3^- and the nitrification of NH_4^+ in the deeper waters. Under stratified conditions, however, NO_3-N usually decreased in the anoxic hypolimnion, a consequence of the cessation of microbial nitrification reactions and of an increase in denitrification.

Epilimnetic concentrations of NO_3-N were variable but were nearly always lower at the surface than at 3 and 6 m, indicating nitrogen depletion by phytoplankton. Note that this phenomenon was most accentuated between February

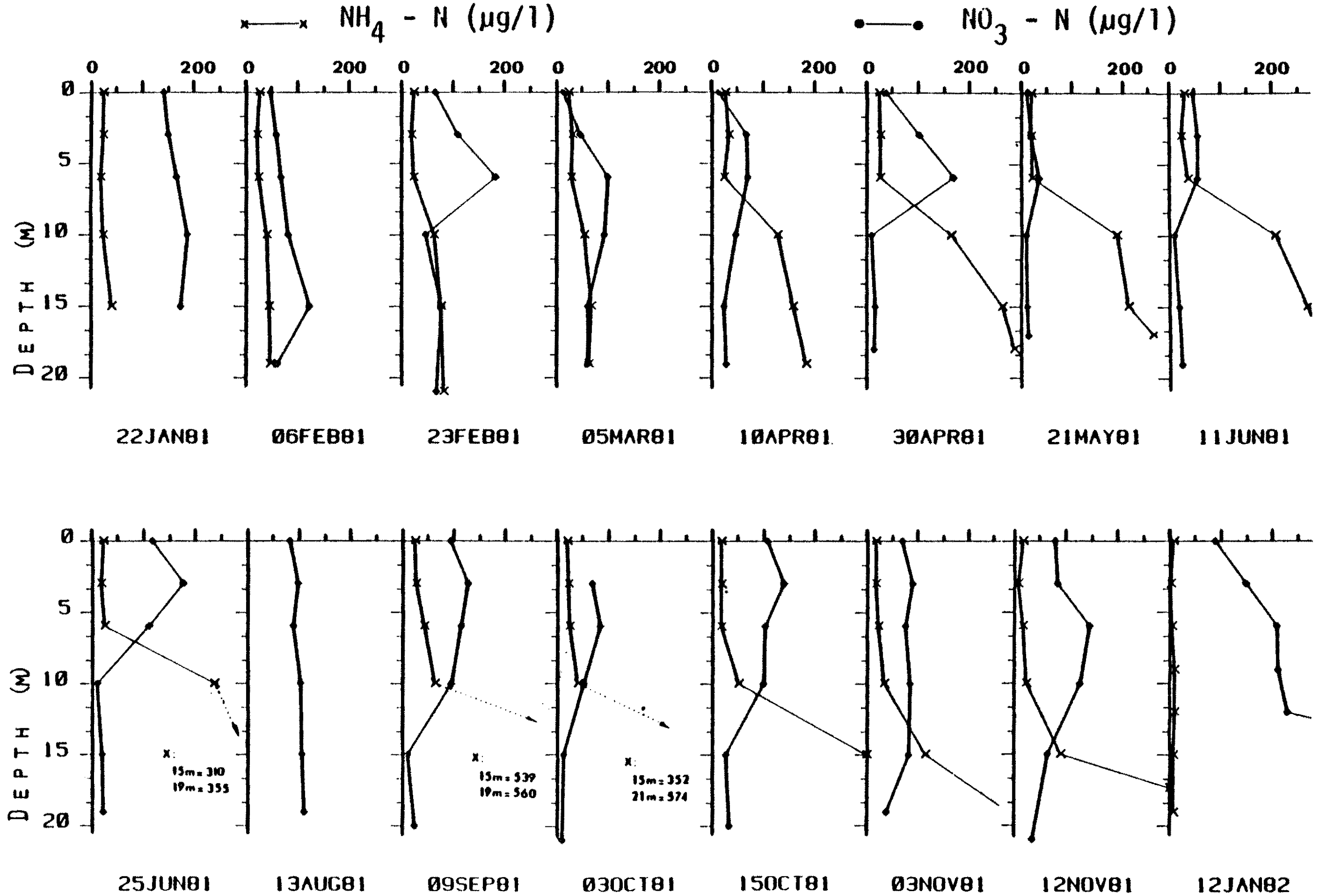


Figure 7.18: Depth profiles of inorganic nitrogen, L Yure index station.

Figura 7.18: Perfiles de profundidad de nitrógeno inorgánico en la estación indice del L. Yure.

and April, when primary productivity (and thus presumably NO_3^- uptake) was highest (Fig. 7.23). Also serving to emphasize this trend are the NO_3-N and primary productivity profiles for 29 April 1982 (Fig. 7.22, Table 7.6). On this date, there were high rates of photosynthesis down to below 5 m, a pattern that had never been previously observed in L. Yure. There was a correspondingly marked depletion of NO_3-N between 0 m and 6 m at this time.

Loading rates of inorganic nitrogen were highest during the wet season (Fig. 7.16), although NO_3-N concentrations in the inflowing streams tended to be highest from August to December or December to January in 1980 and 1981, respectively (Fig. 6.4). Lowest loading rates occurred from March to May, the same period in which rates of primary production were highest. Thus the demand:supply ratio for NO_3-N was also greatest at this time, presumably further accentuating the trend towards surface depletion of NO_3-N.

A comparison of the NO_3-N concentrations of the streams flowing into L. Yure with those of the canal outflow illustrates the influence of the phytoplankton community in reducing levels of inorganic nitrogen in the reservoir (Fig. 6.4). Peak NO_3-N concentrations were lower in canal water than in stream water and the presumed high NO_3-N uptake rates during March-May were reflected in the low outflow concentrations at that time.

7.4.4.1 <u>N:P ratios</u>: The ratio of inorganic nitrogen to total phosphorus in epilimnetic water varied greatly between sampling dates. The mean ratio was 8.9 (standard deviation = 6.6, N = 44), which can be compared to the mean value of 15.2, 12.6, and 8.1 for Q. Sin Nombre, Q. del Cerro and Q. Tepemechín, respectively. The lower lake value reflects the reduction in NO_3-N resulting from the uptake of this nutrient by phytoplankton. See section 9 for further discussion of N:P ratios.

7.4.5 Iron

The influence of oxygen on the solubility of iron and the interrelationship between iron and phosphorus have already been discussed (see sections 7.4.2 and 6.2.9), and do not require further review here. Iron is an essential micronutrient for aquatic organisms and is of special interest in L. Yure since bioassay experiments have indicated that ambient concentrations can be limiting for algal primary productivity (section 7.6). Although iron is present in oxygenated water mainly as colloidal particles of $Fe(OH)_3$, small amounts may be chelated to dissolved organic compounds (Sakamoto and Kamuya 1981, Goldman and Horne 1983, Wetzel 1983).

A representative series of depth profiles of iron concentration is shown in Fig. 7.19. The seasonal trend is exactly that expected from a knowledge of iron solubility. Epilimnetic concentrations were always low, especially during the dry season. Wet season concentrations were slightly higher, presumably a result of increased loading from the tributaries (Fig. 7.16). During periods of complete mixing, iron concentrations were uniformly low throughout the water column. When stratification was established and the hypolimnion became anoxic, the concentration of iron increased below the thermocline as the insoluble ferric form was reduced to the soluble ferrous form. Comparison of Fig. 7.19 with Fig. 7.7 clearly demonstrates the inverse relationship between iron and oxygen.

7.4.6 Silica

Silica (SiO_2) is especially important for the diatoms (Bacillariophyceae), a group of algae which use it in the synthesis of frustules, a hard "case" which surrounds the algal cell. The relationship between SiO_2 levels and diatom populations has been studied in many lakes. Typically, high diatom densities significantly reduce ambient concentrations, often to levels which in turn lead

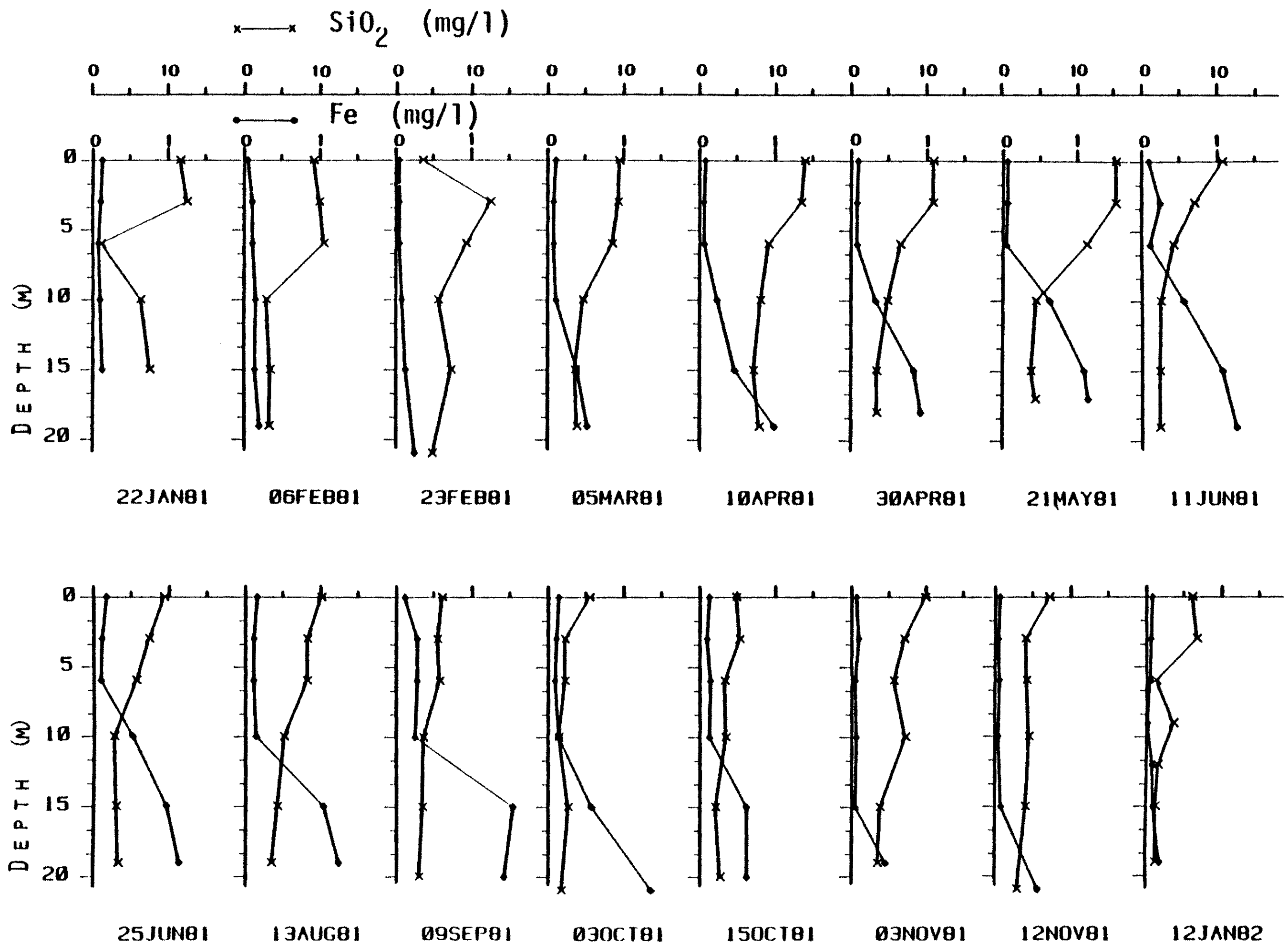


Figure 7.19: Depth profiles of silica and iron, L. Yure index station.

Figura 7.19: Perfiles de profundidad de sílice e hierro en la estación índice del L. Yure.

to dramatic decreases in the diatom populations (Lund 1964). Diatom cells are relatively heavy (because of the silicaceous frustules), and as they sediment out of the epilimnion, they transport SiO_2 downwards to the hypolimnion and the sediments. Some mineralization of the diatom frustules occurs in the hypolimnion, releasing SiO_2 which can then be circulated back to surface waters at turnover. Significant amounts of SiO_2 remain permanently as particulate matter within the sediment, providing an indelible record of diatom species composition through time.

Because of the uptake of SiO_2 by phytoplankton and the subsequent sedimentation of these cells, concentrations of dissolved SiO_2 are typically lower in the epilimnion than in the hypolimnion. SiO_2 profiles at the L. Yure index station are shown in Fig. 7.19, and the entire data record is presented in Table 7.6. The usefulness of these data is restricted, however, since total, and not dissolved, SiO_2 was measured. Thus, concentrations include SiO_2 present in the water itself and that contained within algal cells.

No clear seasonal variations were observed, either for average concentrations or for distribution with depth. Epilimnetic concentrations were typically higher than hypolimnetic ones, mean values for 1981 being 9.2 ($\pm$3.2) and 3.6 ($\pm$1.7) mg/l^{-1} at the surface and one meter above the bottom, respectively. This pattern, the opposite of that usually observed for dissolved SiO_2, may in part reflect the recycling of SiO_2 within the epilimnion. That is, before dead cells (diatoms) sink into the hypolimnion, some of the SiO_2 they contain is liberated to the surrounding water and taken up by living cells. This recycling, combined with the continual input of SiO_2 to the epilimnion from streams, would probably tend to maintain epilimnetic concentrations at higher levels than those of the hypolimnion. However, diatom cell densities were generally low in L. Yure (section 7.7) and so the primarily epilimnetic flow of water through the reservoir was probably the major factor influencing the depth distribution of SiO_2.

7.4.7 Sulphate and Sulphide

Sulphate ($SO_4^=$) and sulphide ($S^=$) were not measured routinely in L. Yure, but the data that were collected are discussed here.

Sulfide concentrations (primarily H_2S) are summarized in Table 7.7. Hydrogen sulfide is produced from the degradation of sulphur-containing organic matter (proteins) and accumulates in the absence of oxygen. Table 7.7 shows that significant amounts of H_2S were only present in anoxic hypolimnetic water. It is interesting to note that concentrations were much higher on the one sampling date in 1982 than in 1981. While it is impossible to adequately evaluate between-year differences, in the absence of a more extensive data-base, the higher 1982 concentrations suggest an increased input of organic matter to the hypolimnion that year. Such an increase could have been derived from the high levels of primary production observed during February - June 1982. It has

Table 7.7. Sulphide concentrations at the L. Yure index station.

Tabla 7.7: Concentraciones de sulfuro en la estación índice del L. Yure.

Date	Sulphide Concentration (ug/l)				
	Depth: 0m	5m	10m	15m	Bottom - 1m
23/VII/81	0	0	8	26	--
10/IX/81	2	4	2	43	54
4/XI/81	2	2	3	3	34
29/IX/82	0	0	0	913	926

been previously suggested that the higher productivity levels also may have been responsible for the elevated hypolimnetic PO_4-P concentrations during June - September 1982 (section 7.4.3).

7.4.8 Magnesium, Calcium, Sodium and Potassium

Concentrations of these metal cations are presented in Table 7.6. In general, they closely reflected the concentrations of the streams flowing into the reservoir (Tables A2.16-18). There were almost no consistent trends, either between sampling dates or between depths. The uniformity of concentrations with depth indicate that these micronutrients were present at levels higher than those required by the biota.

7.4.9 Synoptic Studies

In a dendritic reservoir it is likely that the amount of spatial heterogeneity (i.e. difference in parameter values between different points in the lake) will be high relative to that characteristic of a more "open" lake. This results from the disproportionate influence of individual streams on the water quality of the particular reservoir branch that they flow into. Differences in the flow regimes and water quality of Q. del Cerro and Q. Tepemechín, for example (Fig. 6.4), might be expected to result in variation between the QdC and QT branches of L. Yure.

Although no in-depth, systematic study was carried out on inter-station variability in L. Yure, synoptic samples were taken on a number of occasions. Data from a few of the synoptic sampling dates are presented here in order to illustrate the range of variation possible. Since a variety of interacting factors influence water quality, it is difficult to provide a detailed explanation of the observed between-station differences, in the absence of a more extensive data-base. Reference, however, is made to section 7.4.2, where the influence of river underflow on oxygen concentrations is discussed. It is likely that between-station variation was often a transient phenomenon in L. Yure, because of the relatively rapid through-put of water, especially after major storm events. Fig. 7.20 presents profiles of dissolved oxygen at four stations in the lake on five dates. Fig. 7.21 shows nutrient concentrations in the three main branches of the reservoir as percentages of those at the index station. Discussion of primary productivity and zooplankton synoptic data is deferred to sections 7.5 and 7.7.

7.4.10 Nutrient Budgets

Estimation of the flux of nutrients through a reservoir system is potentially of much interest in terms of understanding nutrient dynamics and their influence on the productivity of the lake ecosystem. Such an understanding is necessary for the effective management of a reservoir.

A considerable amount of effort, however, has to be invested in any study designed to work out even a reasonably accurate nutrient budget for a lake. Because of the other demands of the El Cajón program, it was not possible to carry out a monitoring program that was sufficiently intensive to allow the construction of a realistic nutrient budget for L. Yure. For example, there were no frequent measurements of discharge rates for the inflowing streams and, undoubtedly, major storm events were often "missed" with the sampling schedule employed. Single heavy storms often contribute a large proportion of the total annual loading of particulate matter and associated nutrients to aquatic systems (sections 6.2.6 and 6.2.7).

Average daily inputs and outputs for L. Yure of inorganic nitrogen [NO_3-N + NH_4-N], total phosphorus and iron were estimated for various periods in 1981 and 1982, by multiplying mean nutrient concentrations by mean daily discharges. Total input represents the summed inputs of the three main tributaries. The results are presented in Table 7.8. Note that no attempt has been made to

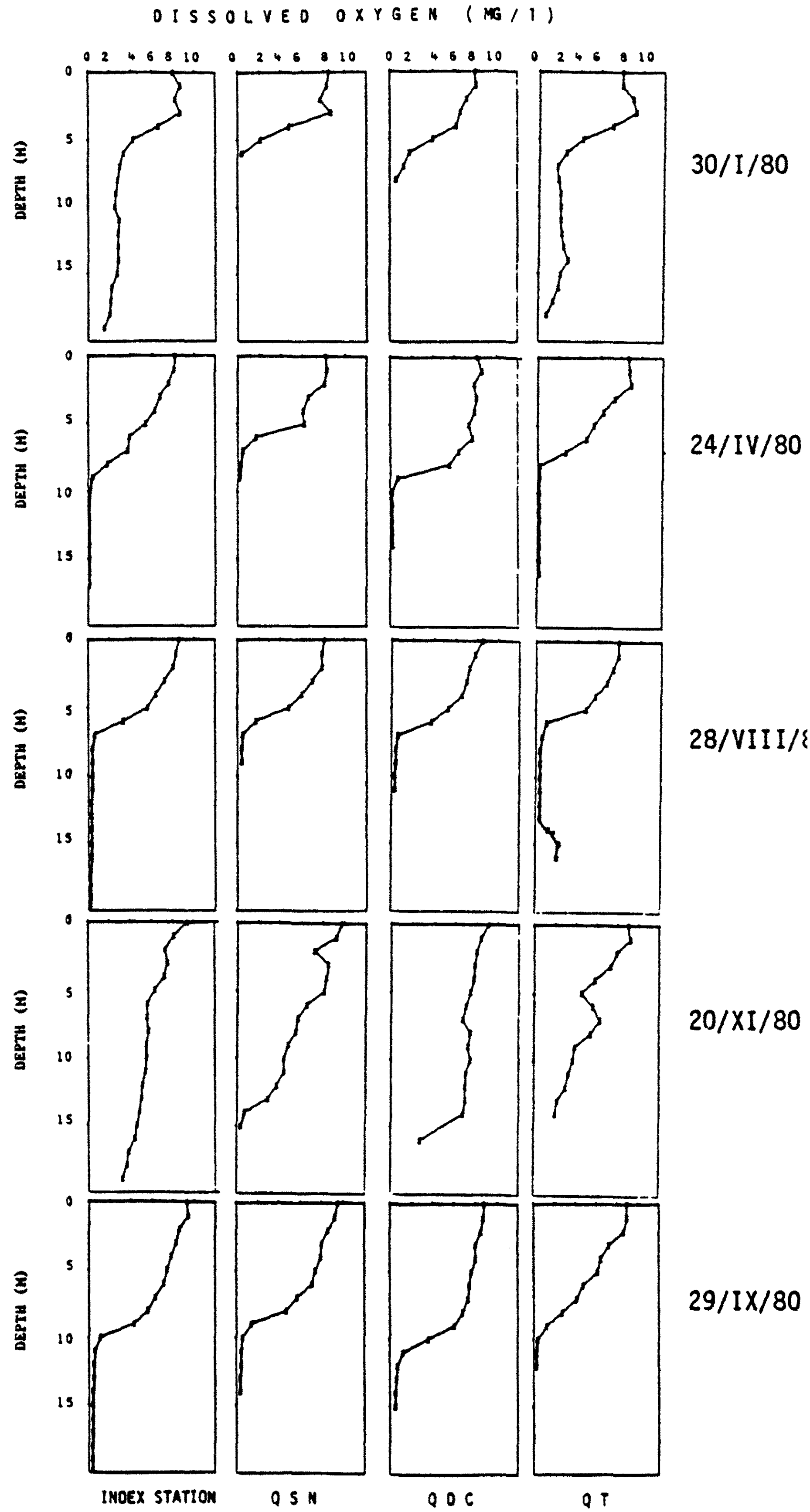
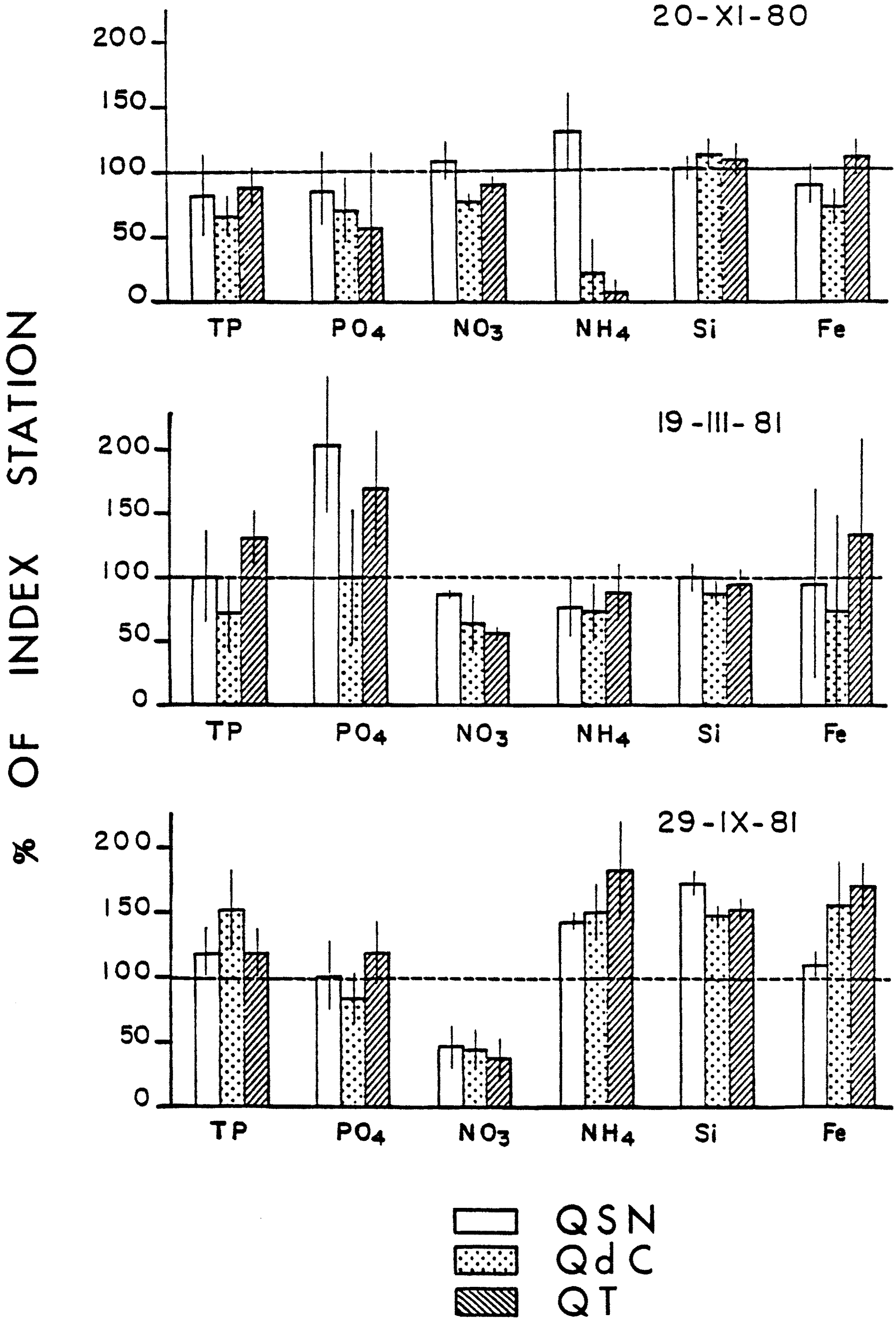


Figure 7.20: Dissolved oxygen profiles at four stations in L. Yure.

Figura 7.20: Perfiles de oxígeno disuelto en cuatro estaciones del L. Yure.

Figure 7.21: Nutrient concentrations in the three main branches of L. Yure expressed as a percentage of those at the index station.
(Histograms represent mean epilimnetic concentrations ± 1 compounded standard deviation).

Figura 7.21: Concentraciones de nutrientes en las tres ramas principales del L. Yure, expresadas como porcentajes de aquellas de la estación índice.
(Las histogramas representan promedios de las concentraciones epilimnéticas ± 1 desviación estandard).



20-XI-80
19-III-81
29-IX-81
% OF INDEX STATION
200
150
100
50
0
TP
PO4
NO3
NH4
Si
Fe
QSN
QdC
QT

Figure 7.21

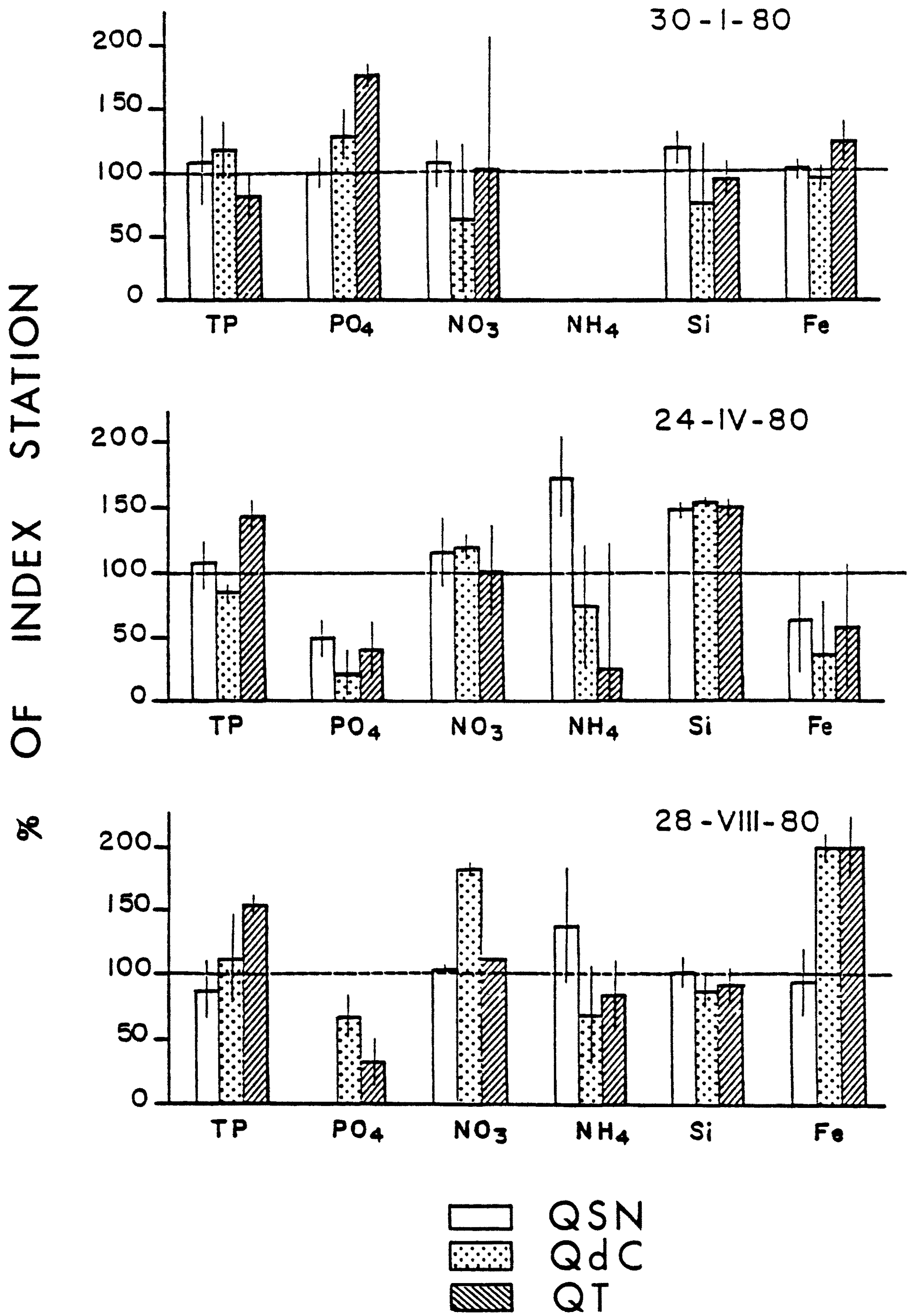


Figure 7.21 (cont.)

Table 7.8: Estimated daily input and output of inorganic nitrogen, phosphorus and iron for L. Yure.

Tabla 7.8: Estimacion de la importación y exportación diaria de nitrógeno inorgánico, fósforo e hierro en el L. Yure.

Period	Inorganic Nitrogen (10^3 g/day)		Total Phosphorus (10^3 g/day)		Total Iron (10^3 g/day)	
	1*	0*	1	0	1	0
1981						
22/I - 6/II	20.93	19.65	2.68	2.56	13.29	22.6
7/II - 23/II	19.11	45.69	2.57	6.15	11.12	54.9
24/II - 5/III	36.32	46.08	2.68	3.49	15.60	50.2
6/III - 19/III	45.36	6.74	1.38	1.29	11.21	16.3
20/III - 10/IV	10.26	3.75	1.17	1.85	5.36	10.1
11/IV - 30/IV	9.28	3.66	0.94	1.68	4.00	9.1
1/V - 21/V	7.17	2.26	1.48	2.26	2.86	7.5
22/V - 11/VI	17.92	5.61	3.58	5.61	8.09	21.5
12/VI - 25/VI	43.62	26.81	4.87	9.07	19.21	57.9
26/VI - 9/VII	39.95	32.79	9.90	14.84	12.71	39.7
10/VII - 28/VII	36.97	44.02	12.51	19.23	17.42	67.4
29/VII - 13/VIII	49.97	99.27	13.06	27.56	33.46	176.0
14/VIII - 9/IX	47.75	93.13	12.96	18.09	35.05	103.9
10/IX - 29/IX	48.13	64.57	4.47	6.95	28.70	59.2
30/IX - 15/X	49.54	72.93	4.52	9.67	27.25	96.7
4/XII - 15/XII	40.57	24.94	2.91	2.99	5.82	13.8
1982						
16/XII - 12/I	63.48	37.29	2.50	2.27	6.61	13.6
13/I - 23/II	36.59	24.98	3.08	3.76	6.38	14.7
24/I - 18/III	20.54	13.07	2.95	3.14	4.17	9.3
19/III - 29/IV	12.13	10.07	1.54	2.22	3.00	8.8
30/IV - 27/V	14.56	27.45	3.35	9.75	6.32	47.0
28/V - 22/VI	53.77	59.39	9.55	14.78	20.88	92.4
23/VI - 20/VII	44.27	44.06	4.50	5.18	18.21	48.6
21/VII - 18/VIII	23.12	31.42	2.51	2.62	11.21	30.5
19/VIII - 28/IX	27.43	36.15	3.09	3.38	13.07	44.2

* 1 = Loading from Q. Sin Nombre, Q. del Cerro and Q. Tepemechin

0 = Output from canal

(See text for further explanation of table) calculate total annual input or output, since the canal gate was closed for a period during the latter part of 1981 and thus no concentration or discharge data are available for that time. Values in the table refer to estimated average daily fluxes during the period under consideration. This nutrient budget is crude, and differences between input and output should not necessarily be taken to indicate net export or net storage of a nutrient. Total phosphorus output, for example, usually exceeded input, especially during the wet season. This almost certainly resulted from an underestimation of the input component because of insufficiently frequent stream sampling. Because the Yure-Yojoa canal represents an epilimnetic outflow from the reservoir, net storage of nutrients within the system would be more likely than net export. The whole area of nutrient budgets is one which would represent a very productive and useful avenue of future research in the El Cajón and Yure reservoirs (see sections 9 and 3).

7.5 PRIMARY PRODUCTION

In lakes without extensive beds of macrophyte plants, phytoplankton represent the major producers of organic matter. With steeply-sloping shorelines, typical of L. Yure and the El Cajón reservoir, pelagic (open-water) primary production becomes especially important. Rates of primary production (PPR) depend on a variety of factors, including nutrient concentrations, temperature, surface light intensity and turbidity of the water. Turbidity includes a biogenic component (the algal cells themselves) and an abiogenic component (mineral particles). High levels of biogenic or abiogenic turbidity sometimes result in light being a factor which limits PPR (see section 9).

Primary production was routinely measured at the L. Yure index station and occasionally at other stations in the reservoir. Index station measurements are summarized in Table 7.9 and Fig. 7.23. Fig. 7.22 presents a series of profiles

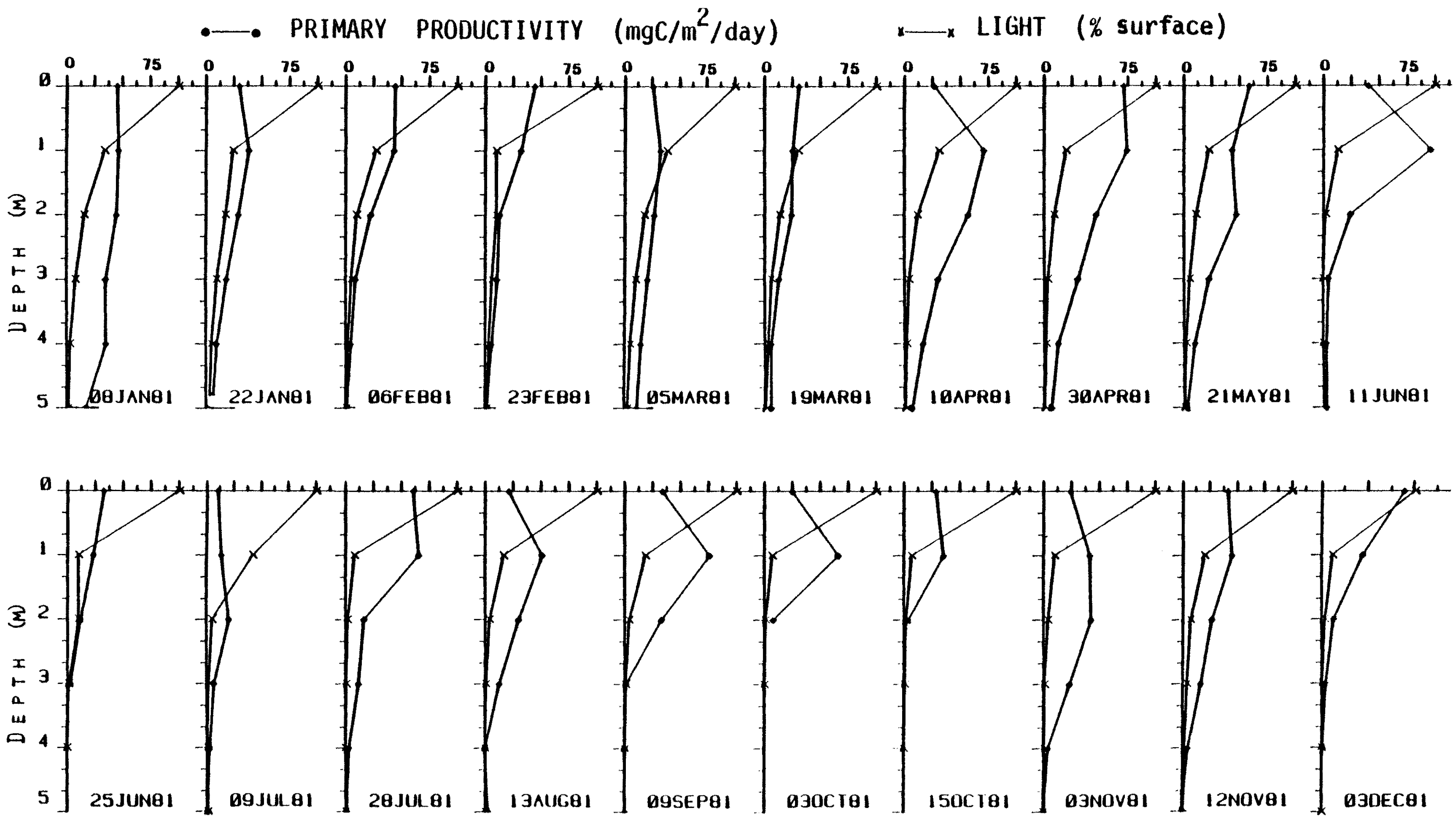


Figure 7.22: Depth profiles of primary productivity and light, L. Yure index station.

Figura 7.22: Perfiles de profundidad de productividad primaria y luz en la estación índice del L. Yure.

Table 7.9: Primary production, L. Yure index station.

Tabla 7.9: Productividad primaria en la estación índice del L. Yure.

	1980 26/VI	16/VII	7/VIII	18/IX	9/X	30/X	20/XI	10/XII	1981 8/I
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	38.5	44.7	42.9	46.5	27.2	47.9	52.7	43.3	45.1
1 m " " "	25.4	39.3	20.2	33.1	4.4	38.7	32.6	30.0	46.3
2 m " " "	20.0	23.7	3.2	2.3	0.2	6.9	5.0	14.0	44.4
3 m " " "	17.5	14.8	0.2	0.6	0.1	0.8	1.1	5.0	34.8
4 m " " "	7.2	6.8	-	-	-	-	-	1.2	35.1
5 m " " "	1.1	2.5	-	-	-	-	-	0.2	16.8
6 m " " "	0.6	0.8	-	-	-	-	-	0.0	9.6
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	117.2	165.8	137.4	149.0	146.3	163.3	119.0	85.3	226.7
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	703.2	994.8	412.3	447.1	48.8	489.8	356.9	512.0	1360.0
Efficiency ($\times 10^{-4}$ per (calorie of light)	1.27	2.01	0.73	1.54	0.86	1.64	1.20	1.88	3.63
Secchi Depth (m)	1.5	2.3	0.85	0.6	0.8	1.1	0.8	1.4	3.8
Total light for day (Langleys)	555	494	565	290	170	298	298	272	375

	1981 22/I	6/II	23/II	5/III	19/III	20/III	21/III	10/IV	30/IV
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	29.9	44.3	44.0	25.0	30.4	41.7	19.5	26.9	70.8
1 m " " "	38.7	43.7	31.4	31.8	25.4	30.1	67.1	71.1	74.1
2 m " " "	28.8	22.3	12.8	26.8	23.6	16.1	57.0	56.7	46.6
3 m " " "	18.3	8.8	10.9	20.6	12.6	5.9	38.8	30.3	29.8
4 m " " "	9.8	4.5	5.6	14.9	6.0	3.1	22.3	16.6	12.7
5 m " " "	6.0	1.6	2.4	11.6	5.6	2.3	22.6	6.9	6.7
6 m " " "	3.5	0.5	0.8	5.4	2.9	0.8	12.8	-	2.0
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	94.7	151.0	124.5	145.7	157.6	169.2	319.1	287.9	213.9
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	946.7	905.6	746.8	874.0	945.7	1014.9	1914.4	1439.5	1283.4
Efficiency ($\times 10^{-4}$ per (calorie of light)	2.92	3.47	1.91	1.71	2.64	2.84	3.51	3.60	2.85
Secchi Depth (m)	2.7	2.2	2.3	3.0	2.6	2.3	-	1.4	1.8
Total light for day (Langleys)	324	261	392	511	358	358	545	400	451

	1981 21/V	11/VI	25/VI	9/VII	28/VII	13/VIII	9/IX	3/X	15/X
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	59.0	40.6	32.9	10.2	60.4	21.6	34.1	25.1	28.4
1 m " " "	43.6	96.4	23.5	13.6	65.8	51.2	75.8	66.5	36.0
2 m " " "	47.3	24.4	11.4	20.6	16.1	29.7	32.6	8.2	3.7
3 m " " "	21.7	5.1	3.1	7.3	11.4	12.1	1.0	-	-
4 m " " "	9.3	2.4	-	3.2	3.3	0.3	0.1	-	-
5 m " " "	3.3	2.5	-	1.0	0.6	2.5	0.0	-	-
6 m " " "	7.1	1.3	-	0.7	0.0	0.2	0.0	-	-
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	205.0	181.1	167.1	69.6	165.9	113.5	159.5	278.1	170.4
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	1229.8	1086.8	501.2	417.9	995.6	681.2	957.0	556.3	340.8
Efficiency ($\times 10^{-4}$ per (calorie of light)	2.33	2.55	1.13	0.78	2.25	1.57	1.85	1.63	1.23
Secchi Depth (m)	1.75	1.1	0.8	1.3	0.75	1.0	0.9	1.0	0.95
Total light for day (Langleys)	528	426	443	539	443	434	517	341	278

Table 7.9 (cont.)

	1981 3/XI	12/XI	3/XII	1982 12/I	23/II	18/III	29/IV	27/V	22/VI
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	24.0	40.7	88.5	30.0	39.5	35.4	101.9	71.4	32.8
1 m " " "	41.7	44.7	43.7	71.8	82.1	91.0	139.0	116.8	58.8
2 m " " "	41.9	26.0	12.4	38.2	43.1	82.7	147.4	104.9	63.7
3 m " " "	23.1	16.2	4.9	20.3	22.1	40.4	82.7	32.7	21.7
4 m " " "	3.5	5.3	1.0	18.4	14.7	19.6	117.3	15.5	5.3
5 m " " "	0.6	1.3	-	27.2	5.1	19.5	57.6	3.4	0.9
6 m " " "	0.1	0.4	-	17.5	2.1	10.9	47.3	0.3	0.1
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	140.2	139.5	179.6	229.9	221.5	325.1	751.4	338.3	198.0
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	840.9	836.7	718.2	1379.7	1328.7	1950.3	4508.1	2029.8	1187.8
Efficiency ($x10^{-4}$ per (calorie of light)	2.09	4.47	3.28	3.95	3.26	3.95	11.30	6.61	2.60
Secchi Depth (m)	1.6	2.0	1.35	2.2	2.2	3.2	-	1.0	1.1
Total light for day (Langleys)	403	187	219	349	408	494	399	307	457

	1982 20/VII	18/VIII	28/IX	12/XI	22/XII	1983 21/I
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	26.0	4.8	14.4	10.4	11.0	10.5
1 m " " "	11.8	4.3	15.9	8.2	22.4	9.7
2 m " " "	10.6	10.4	8.3	6.7	22.2	10.4
3 m " " "	4.0	6.5	9.3	2.7	15.1	7.5
4 m " " "	3.5	1.0	4.6	-	7.9	11.2
5 m " " "	2.6	0.3	1.2	-	2.8	8.5
6 m " " "	1.8	0.0	0.2	-	0.9	2.5
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	62.4	28.4	45.5	62.6	85.0	58.2
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	374.4	170.4	273.2	187.9	509.9	349.1
Efficiency ($x10^{-4}$ per (calorie of light)	0.76	0.34	0.71	0.71	1.60	0.90
Secchi Depth (m)	-	1.6	2.3	2.6	2.1	4.3
Total light for day (Langleys)	494	494	384	263	318	386

showing depth and seasonal variation in PPR. Rates of PPR as measured by the ^{14}C technique are usually considered to represent approximate net production, i.e. production - (respiration + extra-cellular release of soluble organic carbon).

The reduction in PPR with depth usually closely followed the decrease in light; the former, of course, was a result of the latter. In general, most of the PPR in L. Yure occurred within the upper 3 m of the water column, although significant carbon fixation was often measured down as far as 6 m (i.e. to the lower limit of the euphotic zone). On some dates (e.g. 10/IV/81 and 11/VI/81, Fig. 7.22, the highest rate of PPR was observed at an intermediate depth. This phenomenon is frequently observed in lakes under conditions of high incident solar radiation. It often results from the inhibitory effect of high light levels on some of the chemical reactions involved in photosynthesis and is termed photo-inhibition. (This effect may be augmented by the methodology involved in measuring PPR, i.e. enclosure of phytoplankton in a bottle and maintenance of the sample at one depth. Normally, algal cells are circulated through the epilimnion by wind mixing and thus do not necessarily experience very high light conditions for long, continuous periods of time). Highest phytoplankton biomass at intermediate depths may also contribute to sub-surface PPR peaks.

Seasonal variation in PPR is summarized in Fig. 7.23. The overall trend was for higher production from March to June, the period when light levels were highest and abiogenic turbidity was reduced. (Compare with seasonal variation in extinction coefficients, Fig. 7.11.) The record for 1981 most clearly illustrates the interrelationships of the various factors (presumably) influencing PPR.

The following "explanation" of the 1981 record only represents a series of

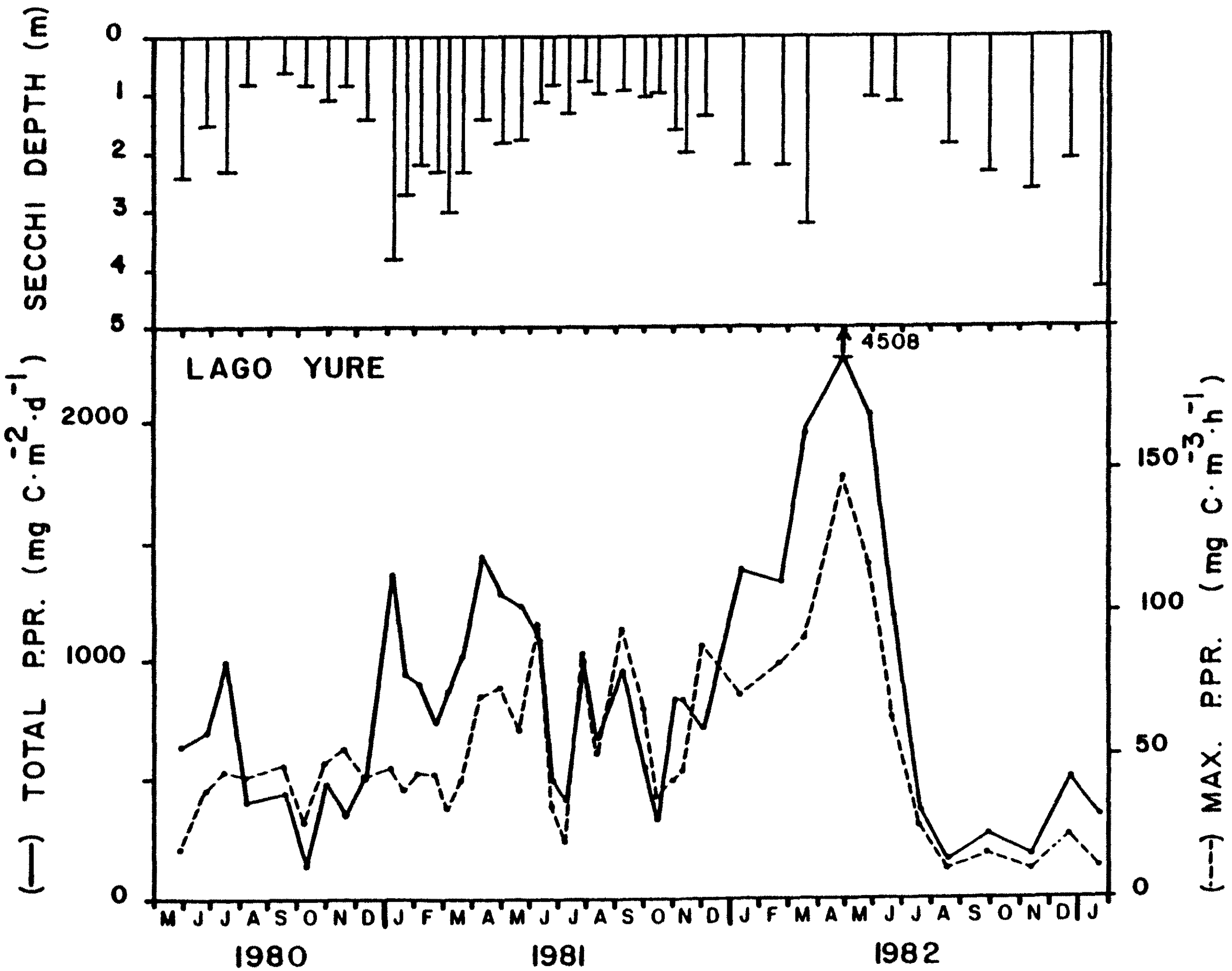


Figure 7.23: Seasonal variation in primary productivity and Secchi depth, L.Yure index station.

Figura 7.23: Variación estacional de productividad primaria y profundidad de Secchi en la estación índice del L. Yure.

hypotheses -- no experimental work could be carried out to investigate, in detail, the factors involved. Interpretation is, however, based on many years of experience with PPR data.

In January, the lake had recently mixed, re-introducing nutrients to the surface waters and stimulating productivity. Water transparency was high (Secchi depth = 3.8 m), allowing significant PPR to occur down to 6 m. Thus, although the average rate of PPR at any depth (mg $C/m^3/d$) was not high, total areal PPR (mg $C/m^2/d$) did exhibit a peak at this time. After stratification was established, both nutrient concentrations in the euphotic zone (Fig. 7.15 and 7.18) and PPR decreased. Higher light levels during March-May led to an increase in both total PPR and the maximum value observed at any depth (P_{max}). Later on, in the wet season, suspended sediment input from the streams increased turbidity (higher extinction coefficients, Fig. 7.11) and led to a general reduction in PPR. During this period, the ratio of P_{max} to total (areal) PPR was higher than in the dry season, indicating high productivity in the surface layers and a rapid decrease with depth (Fig. 7.22).

PPR decreased in September and October, presumably because of lower light levels (nutrient concentrations were not especially low at this time). After October, transparency began to increase and, with it, total PPR.

Although the seasonal pattern of PPR was similar in each of the three years, the dry season peak in 1982 was considerably higher than in the two previous years. Total PPR on 29/IV/82 was over twice the next highest value measured in L. Yure. Transparency was relatively high on that date (Fig. 7.11), but light levels were lower than on the previous sampling occasion. High productivity rates were measured down to 6 m (Table 7.9). While there is no reason to suspect any gross measurement error for this date, the anomalously high PPR value does suggest that caution should be taken over its interpretation. However, similar depth-specific rates of PPR on 27/V/82, even with the lower level of solar radiation for that day, support the belief that the data for 29/IV/82 were in fact representative of the real situation. Additional evidence comes from the lower inorganic nitrogen concentrations on 29/IV/82, suggesting a high total uptake by phytoplankton (Section 7.4.3.). Unfortunately no chlorophyll data are available from this date to support the PPR measurements, but phytoplankton counts do indicate higher algal biomass at this time (see section 7.7).

Table 7.10: Total primary production, L. Yure index station, 1980-1982.

Tabla 7.10: Productividad primaria total durante los años 1980-1982 en la estación índice del L. Yure.

Period	Primary Production (gC/m^2/2 months)		
	1980	1981	1982
January - February	-	55.50	78.25
March - April	-	80.02	170.04
May - June	45.36	63.21	133.85
July - August	38.96	46.08	25.84
September - October	21.07	39.96	13.82
November - December	34.78	60.43	20.79
Annual total (gC/m^2/yr)	-	345.20	442.59

Production rates decreased precipitously from July 1982. There was a small peak in December, just after the lake had mixed, as seen in previous years.

Dry season productivity rates apparently increased from 1980 to 1982, as indicated in Fig. 7.23 and Table 7.10. In new reservoirs, productivity typically increases over a period of one to a few years as nutrients are leached from flooded soils and vegetation. The increase noted in L. Yure may represent this initial period of higher fertility. However, ambient nutrient concentrations in the lake during this period do not really support this hypothesis. In fact, there are indications that phosphorus is accumulating in the system from external inputs (see section 7.4.3). With a data base spanning just 2 1/2 years, it is not possible to adequately characterize annual trends. It would be very interesting to compare PPR values in 1983 with those from the previous three years. Primary production is further discussed in section 9, where an analysis of the differences between the Yure and Yojoa systems is presented.

7.5.1 Synoptic measurements of primary productivity

On four occasions, PPR was measured in each of the three main branches of L. Yure in addition to the index station. There were no significant between-station differences in PPR on any date. The results from one synoptic sampling are presented in Table 7.11, both as an example of the data collected and to illustrate the influence of high light levels on the distribution of photosynthesis with depth. Note the change in the PPR profile at the index station, when high solar radiation on the third day resulted in photo-inhibition at the surface. (Since there were insufficient bottles to measure PPR down to 6 m at all four stations on the same day, this synoptic was carried out over three days, with an incubation at the index station on each day to control for changes in solar radiation.)

7.5.1 Chlorophyll *a* concentrations

Chlorophyll *a* was not measured on a sufficiently regular basis to allow an adequate correlation between pigment concentrations and seasonal/depth trends in primary production and nutrients. Data are summarized in Table 7.12.

Table 7.11. Primary production at four stations* in L. Yure; March 1980

Tabla 7.11: Productividad primaria en cuatro estaciones en L. Yure, Marco 1980.

Depth (m)	Primary Production ($mgC/m^3/d$)					
	Index (19/III/80)	QSN	Index (20/III/80)	QdC	Index (21/III/80)	QT
0	30.4	32.9	41.7	41.9	19.6	40.6
1	25.4	27.8	30.1	32.9	67.1	66.4
2	23.6	19.6	16.1	18.7	56.9	47.0
3	12.6	16.3	5.9	4.6	38.8	19.6
4	6.0	11.1	3.1	2.3	22.3	7.5
5	5.6	7.8	2.3	1.3	22.6	6.3
6	2.9	4.9	0.8	1.1	12.8	2.1
Total ($mgC/m^2/d$)	945.7	1068.7	1014.9	1141.1	1914.4	1436.8

(*See Fig. 7.1 for station locations)

Concentrations were usually within the range of 1-10 ug/l, which are relatively low, especially in relation to the rates of primary production observed during 1982. Primary production at the index station decreased precipitously between June and July 1982, even though levels of solar radiation were similar in both months. However, there was no corresponding marked change in concentrations of chlorophyll a, which suggests that biomass remained fairly constant while productivity declined, or that the chlorophyll data may not be completely reliable. Possible changes in the photosynthetic efficiency per unit of chlorophyll and the amount of chlorophyll per unit biomass make further interpretation from the present data base difficult.

In limnological studies, fluorescence is often used to estimate chlorophyll concentrations. Unfortunately, data collected during the present study cannot

Table 7.12: Chlorophyll a concentrations, L. Yure.

Tabla 7.12: Concentraciones de clorofila a en el L. Yure.

a) 1980 (Integrated samples from euphotic zone)

Date	Chlorophyll a (μg/ℓ)			
	Index	QSN	QdC	QT
30/I/80	11.5	4.0	12.9	21.0
14/II/80	11.7	14.4	6.8	9.3
13/III/80	--	5.1	5.2	5.8
26/III/80	5.4	4.7	8.3	4.1
24/IV/80	3.9	3.8	4.9	3.2

b) 1982 (Depth-specific samples, Index station)

<table>
<tr><th>Date</th><th colspan="9">Chlorophyll a (μg/ℓ)</th></tr>
<tr><th>Depth(m):</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>9</th><th>12</th></tr>
<tr><td>27/V/82</td><td>9.9</td><td>8.4</td><td>6.8</td><td>4.6</td><td>3.2</td><td>2.6</td><td>0.8</td><td>--</td><td>--</td></tr>
<tr><td>22/VI/82</td><td>3.6</td><td>2.6</td><td>3.4</td><td>3.2</td><td>2.6</td><td>1.6</td><td>0.4</td><td>--</td><td>--</td></tr>
<tr><td>28/VI/82</td><td>3.1</td><td>--</td><td>--</td><td>6.2</td><td>--</td><td>--</td><td>5.2</td><td>3.6</td><td>2.5</td></tr>
<tr><td>1/VII/82</td><td>3.4</td><td>--</td><td>4.3</td><td>--</td><td>11.1</td><td>--</td><td>2.7</td><td>--</td><td>--</td></tr>
<tr><td>20/VII/82</td><td>1.1</td><td>1.7</td><td>0.9</td><td>0.2</td><td>0.1</td><td>--</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td>18/VIII/82</td><td>2.7</td><td>--</td><td>--</td><td>9.1</td><td>--</td><td>--</td><td>3.2</td><td>4.4</td><td>4.2</td></tr>
<tr><td>28/IX/82</td><td>1.7</td><td>1.0</td><td>1.7</td><td>1.5</td><td>2.0</td><td>2.1</td><td>1.7</td><td>--</td><td>--</td></tr>
<tr><td>5/X/82</td><td>3.5</td><td>--</td><td>--</td><td>3.2</td><td>--</td><td>--</td><td>3.6</td><td>3.6</td><td>3.2</td></tr>
<tr><td>20/X/82*</td><td colspan="2">3.1</td><td colspan="2">2.5</td><td colspan="2">1.3</td><td></td><td></td><td></td></tr>
<tr><td>29/X/82*</td><td colspan="2">2.4</td><td colspan="2">2.4</td><td colspan="2">1.3</td><td></td><td></td><td></td></tr>
<tr><td>1/XI/82*</td><td colspan="2">0.6</td><td colspan="2">1.3</td><td colspan="2">2.4</td><td></td><td></td><td></td></tr>
<tr><td>4/XI/82*</td><td colspan="2">7.5</td><td colspan="2">2.8</td><td colspan="2">2.1</td><td></td><td></td><td></td></tr>
</table>

* = Station QT

be used for comparison to the chlorophyll concentrations obtained analytically because the various filters used in the fluorometer were unable to selectively remove the background fluorescence observed both in lake and stream samples.

7.6 NUTRIENT BIOASSAYS

Bioassay experiments are frequently used as a component of lake management studies in order to evaluate which nutrient(s) is (are) limiting to algal primary production. A limiting nutrient is one which, when added to an algal assemblage, leads to an increase in primary production. Generally, the nutrient which is in shortest supply, relative to the demand by the phytoplankton, is limiting to the system (Goldman 1960, 1963).

Several series of bioassay experiments were conducted for this program. Those reported here were designed to identify nutrient limitation in L. Yure. A second set of experiments, not described in detail here but based on similar work in North American and New Zealand lakes (Goldman 1964), investigated the ability of water from the Humuya, Sulaco and Chiquito rivers to stimulate production in the L. Yure phytoplankton assemblage. Results of these experiments indicated that water from all three rivers depressed productivity of L. Yure phytoplankton, even though river water nutrient concentrations were higher than those in the lake. One hypothesis to explain these results might be that suspended sediment in the river water led to an overall reduction in the PO_4-P concentrations of combined lake/river water through adsorption or that they contained inhibiting elements. Further development of these bioassays would represent a useful component in a future research program on the El Cajón reservoir, especially in relation to the role of sediments in the productivity of the new system.

The limiting factor bioassay experiments investigated the influence of a series of nutrients on the L. Yure algal assemblage, during both wet and dry seasons. Table 7.13 lists nutrient spike concentrations and volumes employed. Table 7.14 summarizes the treatments used in a series of four experiments. Treatments labelled "pine", "oak" and "ashes" refer to L. Yure water in which leaves or ash had been leached, aerobically or anaerobically, for eight days. The results which follow have been extracted from a more detailed series of bioassay studies (Knud-Hansen 1983).

Bioassay results are presented as ^{14}C incorporation as a percent of the control for each day filtered. Higher incorporation of ^{14}C represents higher algal production and therefore greater stimulation by the treatment. (Controls were L. Yure water with no nutrient additions. Subsamples were filtered daily from each flask over a period of five days -- see section 5.1.4). Data for day 3 are best used for comparative purposes since they reveal the greatest differences between treatments.

Results from the experiments are summarized in Figs. 7.24-26. In both wet and dry seasons, both P and Fe stimulated primary production, whereas N, on its own or with P, had little effect (experiments 1 and 3). Greatest stimulation was obtained with P + N + Fe (Figs. 7.24a and b). Neither the micronutrient solution nor the silica additions significantly stimulated ^{14}C uptake. (Note that although the Fe spike was made from ferric ammonium sulphate, additional experiments, not reported here, demonstrated that Fe and not NH_4^+ or $SO_4^=$ was responsible for the increased ^{14}C uptake when in combination with P).

Experiment 4 investigated the effects of adding different amounts and ratios of P and Fe. Dark controls were included to account for possible co-precipitation of radioactive bicarbonate with iron which might subsequently be filtered out with the algae. Day 3 results show that P and 2P spikes stimulated carbon uptake equally (Fig.7.25). The 2Fe spike, however, resulted in a greater response than the Fe spike. With the treatments that combined Fe and P,

Table 7.13: Nutrient spike concentrations and volumes used in the algal bioassay experiments.

Tabla 7.13: Concentraciones y volumenes de las adiciones de nutrientes usadas en los bioensayos de algas.

Nutrient	Spike Formula	Spike Concentration (mg/ℓ)	Spike Volume (mℓ)	Conc. in Lago Yure* (μg/ℓ)	Spike + Lago Yure* (μg/ℓ)
P	KH_2PO_4	20	1	20	70
2P		20	2		120
N	KNO_3	60	1	60	210
Fe	$FeSO_4(NH_4) \cdot 6H_2O$	100	1	100	350
2Fe		100	2		600
Si	† $NaSiO_3 \cdot 9H_2O$	1000	12	12000	42000
B	H_3BO_4	32.46		--	32.46+
Mn	$MnCl_2 \cdot 4H_2O$	115.37		--	115.37+
Zn	$ZnCl_2$	1.57		--	1.57+
Co	$CoCl_2 \cdot 2H_2O$	0.354	0.4	--	0.354+
Cu	CuCl	0.004		--	0.004+
Mo	$Na_2Mo_4 \cdot 2H_2O$	2.878		--	2.878+
EDTA	Na•EDTA	58.56		--	58.56+

* Mean epilimnetic concentration

\+ Plus ambient lake water concentration

† Micronutrient solution

Table 7.14: Treatments used in the algal bioassay experiments.

Tabla 7.14: Tratamientos usados en los bioensayos de algas.

	1981		1982	
Experiment Number	1	2	3	4
Date Started	8/VIII	29/VIII	21/III	31/III
Treatment				
P	X		X	X
2P				X
N	X		X	
P+N	X		X	
Fe	X		X	X
2Fe				X
P+Fe				X
P+2Fe				X
2P+Fe				X
2P+2Fe				X
P+N+Fe	X		X	
Si	X			
Micronutrients	X		X	
Pine + O_2		X		
Pine - O_2		X		
Oak + O_2		X		
Oak - O_2		X		
Ashes + O_2		X		
Ashes - O_2		X		

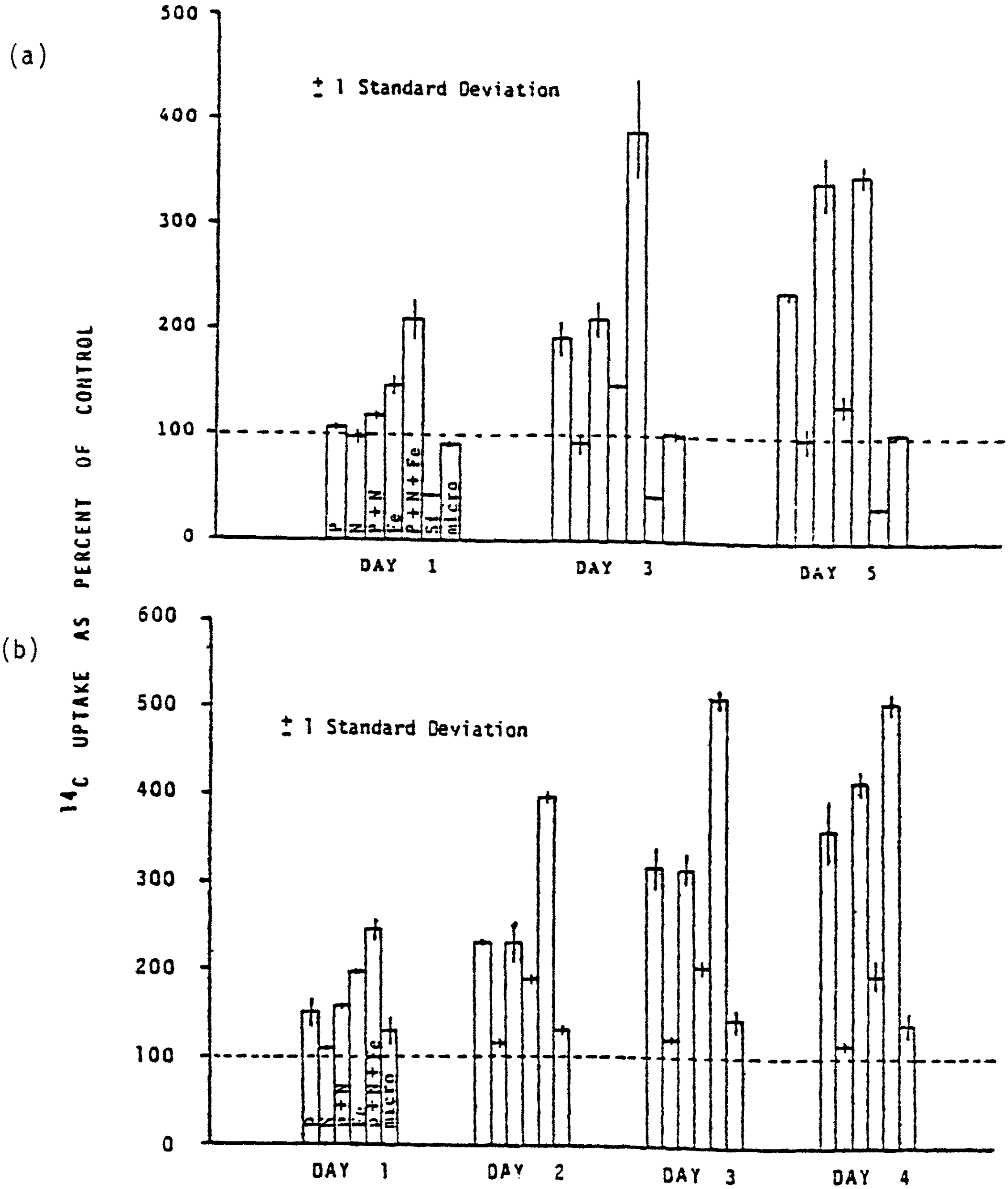


Figure 7.24 a: Results of preliminary wet season algal bioassay (experiment 1) (Spikes are identified in day 1 histogram).

Figura 7.24 a: Resultados preliminares de bioensayos de algas durante la estación lluviosa (experimento 1)
(Adiciones son identificadas el las histogramas del día no. 1)

Figura 7.24 b: Results of preliminary dry season algal bioassay (experiment 3).

Figura 7.24 b: Resultados preliminares de bioensayos de algas durante la estación seca (experimento 3).

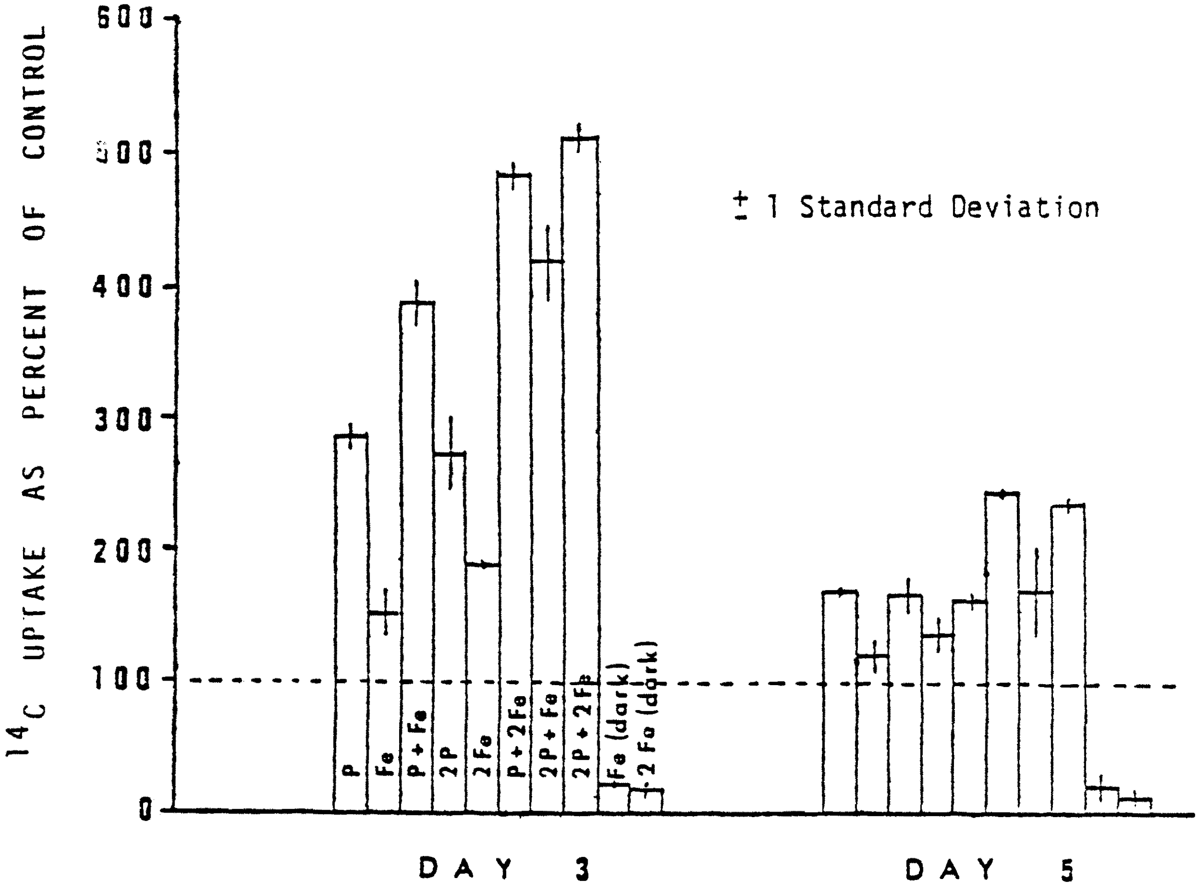


Figure 7.25: Stimulation of primary production in the L. Yure plankton assemblage by different levels of phosphorus and iron (bioassay experiment 4).

Figura 7.25: Estimulación en la productividad primaria en los componentes del plancton del L. Yure por adición de diferentes niveles de fósforo y hierro (bioensayo experimento 4).

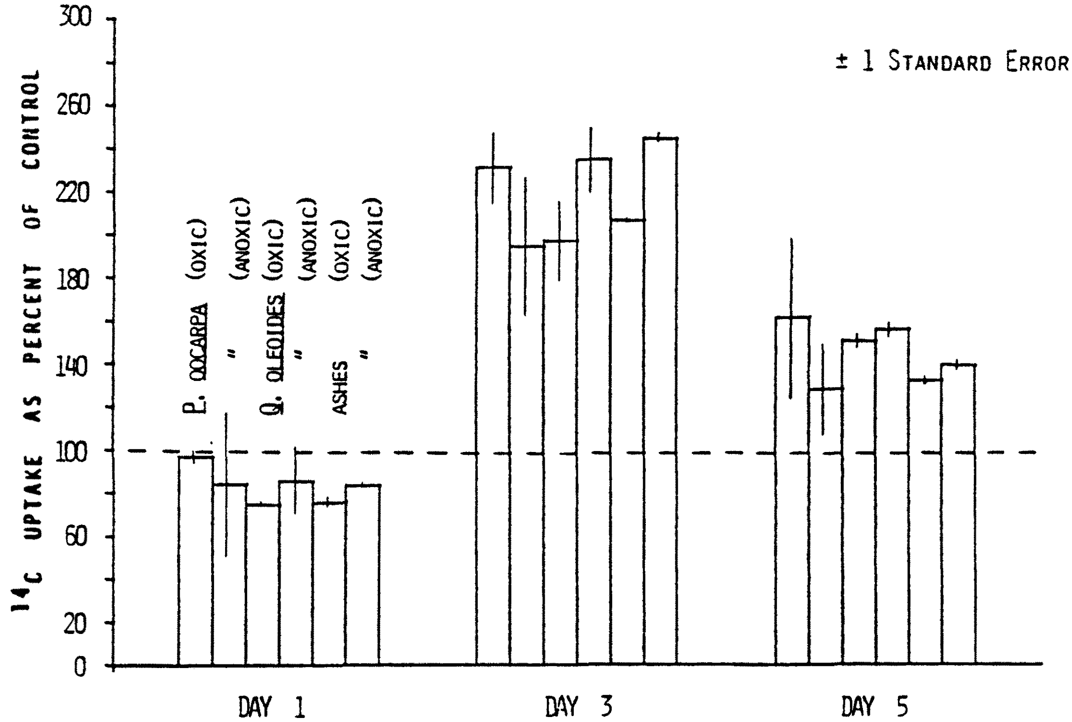


Figure 7.26: Stimulation of primary production in the L. Yure plankton assemblage by pine, oak and ash leachates (bioassay experiment 2).

Figura 7.26: Estimulación de la productividad primaria en los componentes del plancton del L. Yure por hojas de pino y roble y por cenizas (bioensayo experimento 2).

increasing the level of the Fe spike resulted in a positive ^{14}C uptake response for each level of P. However, at each level of Fe there was no response increase by raising the phosphorus spike from P to 2P.

Experiment 2 investigated the effect of pine, oak and ash leachate. It was found that both plant types and their ashes stimulated ^{14}C uptake by about 200% over the control (Fig. 7.26). This experiment illustrates the potential significance of flooded vegetation (whether burnt or not) to the fertility of a new reservoir. Further discussion of nutrient limitation is deferred to section 9.

7.7 PHYTOPLANKTON

The patterns in primary productivity that have been discussed in Section 7.5 were influenced not only by solar radiation, water turbidity and nutrient concentrations, but also the composition of the phytoplankton community. The present section discusses L. Yure phytoplankton community structure and attempts to relate it, where possible, to the observed patterns in primary production. Phytoplankton counts from the L. Yure index station and QSN, QdC and QT are listed in Appendix 4. Note that counts for the first three dates in 1980 were made at Davis, whereas the remaining counts were made in the Santa Cruz laboratory. As has been previously mentioned, taxonomic reference material was very restricted in Honduras and so species identifications were often difficult to make. (There was even some uncertainty with a number of identifications for the Davis-counted samples.) In the lists which appear in Appendix 4, identification is recorded to the species level only in those cases where the organisms apparently fit well into one of the species descriptions appearing in the taxonomic references available in Honduras. Species identifications should therefore be interpreted with some caution.

Phytoplankton counts from the index station for 1981 and 1982 are summarized in Table 7.15. Taxa are listed at the generic level only because of the uncertainty over some species identifications.

The Chlorophyta (the "green" algae) dominated the L. Yure phytoplankton during the period 1980-1982. Small green flagellates (e.g. *Carteria*) were abundant on most sampling dates but did not represent biomass dominants owing to their small size. (Note: *Carteria* should probably be read as *Carteria*-like flagellates; identification, even to the generic level, was not always easy with this group of algae). Larger species, such as *Eremosphaera* spp. and *Cosmarium* spp. were usually more important in terms of biomass.

In contrast to the abundance of the Chlorophyta, diatoms (Bacillariophyceae) and bluegreens (Cyanophyta) were rare. The only common diatom was *Navicula hassica*, which was most abundant during the dry season of 1981, but much less so during the same period in 1980 and 1982. Small blooms of the diatoms *Achnanthes* and *Gyrosigma* were observed in October 1981 and April 1982, respectively. Bluegreens were rare or absent from the samples during much of the period covered by this study. However, on 29/IV/82, there was a small bloom of *Aphanothece*, a colonial member of the order Chroococcales. This genus is similar to *Microcystis* which is often the biomass dominant in Lago de Yojoa. On 29/IV/82 it was relatively abundant throughout the water column (Appendix 4) and, together with *Cosmarium*, *Mallomonas*, *Staurastrum* and *Oocystis*, was presumably responsible for the high levels of primary production observed from 0 m to 5 m on that date (see Table 7.10, section 7.5). Although it is a bluegreen alga, *Aphanothece* is not a genus which fixes nitrogen.

With the existing data base, it is difficult to fully analyze seasonal trends in phytoplankton species composition. In a relatively new, developing reservoir such as L. Yure, it might be expected, *a priori*, that phytoplankton community structure would exhibit considerable between-year variation, as

Table 7.15: Phytoplankton densities (cells/ml), L. Yure, 1981-1982.

Tabla 7.15: Densidades de fitoplancton (células/ml) en el L. Yure, 1981-1982.

	1981											1982					
DATE	8-I	6-II	23-II	19-III	21-V	25-VI	9-VII	13-VIII	9-IX	3-X	12-XI	12-I	23-III	18-III	29-IV	27-V	22-VI
DEPTH (m)	0-6	(0-6)	(0-6)	0-6	(0-2)	(0-4)	0-4	(0-6)	(0-6)	(0-4)	(0-6)	(0-6)	(0-6)	(0-8)	(0-6)	(0-6)	(0-6)
GENUS																	
Chlorophyta																	
Carteria	131	355	502	546	123	222	290	480	115	78	281	287	36	56	176	355	23
Chlamydomonas	419	815	1312	771	219	396	894	148	67	273	155	116	170	161	404	401	59
Chlorogonium	-	-	-	266	-	-	-	-	-	-	-	-	-	-	-	-	-
Chloromonas	-	-	346	11	109	4	14	-	35	28	-	489	3	109	83	129	186
Polytoma	-	-	14	-	-	-	-	1	13	-	2	27	-	-	80	10	4
Sphaerellopsis	-	444	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eudorina	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
Gonium	-	-	64	131	24	-	-	-	5	-	-	-	-	-	-	-	-
Uva	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Asterococcus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	236	1	-
Gleocystis	-	18	-	-	-	-	-	-	-	13	-	-	55	60	-	311	49
Sphaerellocystis	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Mesostigma	-	-	36	-	-	-	-	-	-	-	-	-	6	8	-	-	4
Chlorococcum	-	-	-	-	-	-	-	33	-	-	25	-	-	-	-	-	-
Tetraedron	-	44	28	382	6	1	-	25	11	14	-	11	67	8	-	8	2
Ankistrodesmus	-	-	75	93	115	5	4	2	11	8	-	-	-	161	-	1	137
Closteriopsis	210	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Echinosphaerella	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Eremosphaera	-	-	-	-	298	549	1340	429	882	839	144	120	138	142	-	243	29
Kirchneriella	-	-	-	-	-	1	2	-	-	-	-	-	-	1	18	3	4
Nephrocytium	-	-	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oocystis	13	33	66	158	77	3	17	5	8	3	8	1	-	3	205	6	7
Golenkinia	-	53	122	11	-	4	5	-	-	5	-	11	4	4	-	-	-
Scenedesmus	-	9	12	22	-	-	4	-	-	-	-	19	-	7	24	38	1
Pediastrum	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	154	-
Elakatothrix	-	-	-	-	-	3	2	1	-	-	-	-	-	-	-	-	-
Apatococcus	-	-	-	-	-	-	-	11	-	-	-	-	-	-	-	-	-
Actinotaenium	-	-	17	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Closterium	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Cosmarium	112	7299	382	1410	2861	251	540	288	137	46	437	328	201	262	748	1051	61
Micrasterias	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-
Staurastrum	8	4	53	22	39	-	16	35	128	18	-	14	19	14	193	91	8

Table 7.15 (cont.)

	8-I	6-II	23-II	19-III	21-V	25-VI	9-VII	13-VIII	9-IX	3-X	12-XI	12-I	23-III	18-III	29-VI	27-V	22-VI
<u>Euglenophyta</u>																	
Euglena	-	-	-	77	-	-	3	-	-	-	-	-	-	-	-	-	-
Euglenomorpha	-	14	-	44	-	-	-	-	-	-	-	-	-	-	-	-	-
Trachelomonas	-	89	-	-	-	-	-	-	-	-	-	184	-	-	-	-	-
<u>Pyrrhophyta</u>																	
Gymnodinium	-	39	29	-	-	13	18	3	1	-	5	-	68	112	-	26	19
Peridinium	39	-	5	5	74	36	85	219	77	24	106	27	206	229	-	148	29
<u>Cryptophyta</u>																	
Chroomonas	40	186	27	142	-	134	175	83	57	42	108	58	21	31	89	76	105
Cryptomonas	41	55	25	-	8	-	-	-	-	-	-	9	-	-	-	52	393
<u>Chrysophyta</u>																	
Rhizochrysis	-	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinobryon	173	-	-	-	-	4	27	-	-	-	-	8	-	44	-	-	3
Mallomonas	111	29	76	137	110	52	117	29	33	40	9	83	-	58	523	92	127
Synedra	-	-	3	16	10	-	-	-	-	-	-	29	-	4	-	4	3
Achnanthes	-	2	-	-	-	3	-	-	-	144	-	-	-	-	-	-	-
Cocconeis					7												
Navicula	38	40	27	71	11	5	6	5	-	20	-	6	-	12	-	3	-
Pinnularia	-	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gyrosigma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	101	-	-
Cymbella	-	-	-	-	2	-	-	-	-	-	-	1	-	-	-	-	-
Surirella	-	-	3	-	-	2	2	-	-	4	-	-	-	1	-	-	4
Melosira	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<u>Cyanophyta</u>																	
Aphanothece	-	-	-	-	-	-	-	-	-	-	-	-	-	-	319	-	-
Chroococcus	-	-	-	-	-	73	40	41	-	24	-	-	-	-	-	-	-
Marssoniella	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Microcystis	-	-	-	-	-	-	-		-	-	-	-	-	-	12	-	-
Synechococcus	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-

nutrient regimes etc. change through time. Most of the genera listed in Table 7.15 exhibited considerable variation in abundance between sampling dates. The two most common genera of the larger Chlorophyta, Cosmarium and Eremosphaera (biovolumes of 17034 and 11253 μm^3, respectively, compared to 100-400 μm^3 for most of the flagellates), showed different patterns of seasonal variation. Cosmarium connatum was abundant between February and May in 1981 and again in April 1982. A smaller desmid species (possibly also Cosmarium) was very abundant during February to April 1980 (see Appendix 4).

An especially dense bloom of Cosmarium connatum was noted on 6/II/81 (Table 7.15). Although total primary production on this date was not very high, this was largely because solar radiation was reduced. Production efficiency, however, was relatively high (3.47×10^{-4} per calorie of light), presumably a result of the Cosmarium bloom (Fig. 7.23, Table 7.9). Highest densities of Cosmarium were at the surface and highest primary production was also recorded at 0 m on that date. In May 1981, Cosmarium densities were again high. Cell numbers were greatest at 2 m, which corresponded to a higher rate of primary production at that depth (Fig. 7.22).

In contrast to the dry season dominance by both flagellates and Cosmarium, the most abundant species (and biomass dominant) during the 1981 wet season (May-October) was Eremosphaera sp. This is a large species belonging to the family Oocystaceae and probably was principally responsible for the increase in primary productivity observed between July and September 1981. Note that the subsurface peak in Eremosphaera densities on 9/IX/81 (Appendix 4) was correlated with the metalimnetic peak in primary productivity on that date (Fig. 7.22). Unfortunately, no phytoplankton data are available beyond July 1982, so it is not known if Eremosphaera was as important of a component of the phytoplankton assemblage in 1982 as it was in 1981. Primary production between July and

November 1982, however, was much lower than for the same period in the previous year. The low cell densities (especially of Cosmarium and Eremosphaera) at the end of July 1982 corresponded well with the low production rates at that time.

7.8 ZOOPLANKTON

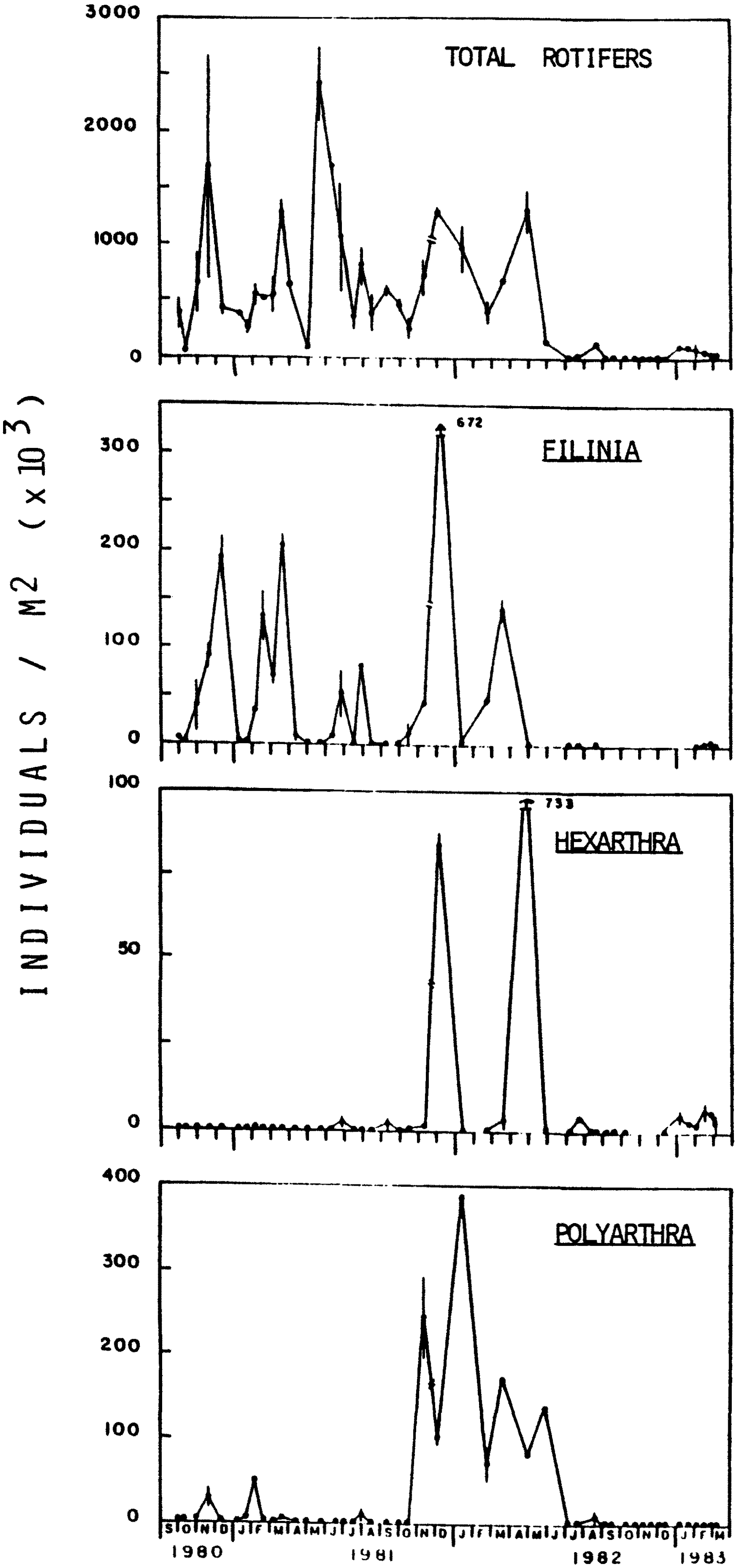
In the absence of filter-feeding herbivorous fish (as is the case in L. Yure and L. de Yojoa), zooplankton represent the major group of organisms which directly harvest organic matter produced in the pelagic, or openwater, zone of a lake. Because of their central position in the food chain, zooplankton can directly influence both the phytoplankton community (by grazing) and the fish community (by representing an important food resource). Zooplankton may at times even have a significant effect on nutrient dynamics within the lake system (by recycling nutrients from ingested phytoplankton back into the water). Thus a knowledge of zooplankton population dynamics and community structure is of importance not only in terms of plankton ecology, but also with respect to the more applied fields of fisheries management and possibly control of lake fertility.

Some very striking changes in the L. Yure zooplankton community occurred during the period of the present study which had a significant influence on some of the fish species inhabiting the lake. This section discusses zooplankton community structure in L. Yure. The influence of zooplankton on the fish populations will be analyzed in section 11.

All of the zooplankton data obtained from the index station in L. Yure are summarized in Appendix 3. Data are presented as the mean number of animals (of two replicate samples) below 1 m^2 of lake surface. Coefficients of variation are also shown, indicating a composite variance derived from sampling error and small-scale spatial heterogeneity. Figs. 7.27-7.29 summarize much of this information.

Figure 7.27: Seasonal variations in the densities of the major zooplankton species, L. Yure index station.

Figura 7.27: Variación estacional en las densidades de las especies principales del zooplancton en la estación índex del L. Yure.



TOTAL ROTIFERS
FILINIA
672
HEXARTHRA
733
POLYARTHRA
INDIVIDUALS / M2 (x 10 3)
3000
2000
1000
0
300
200
100
0
100
50
0
400
300
200
100
0
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M
1980
1981
1982
1983

Figure 7.27

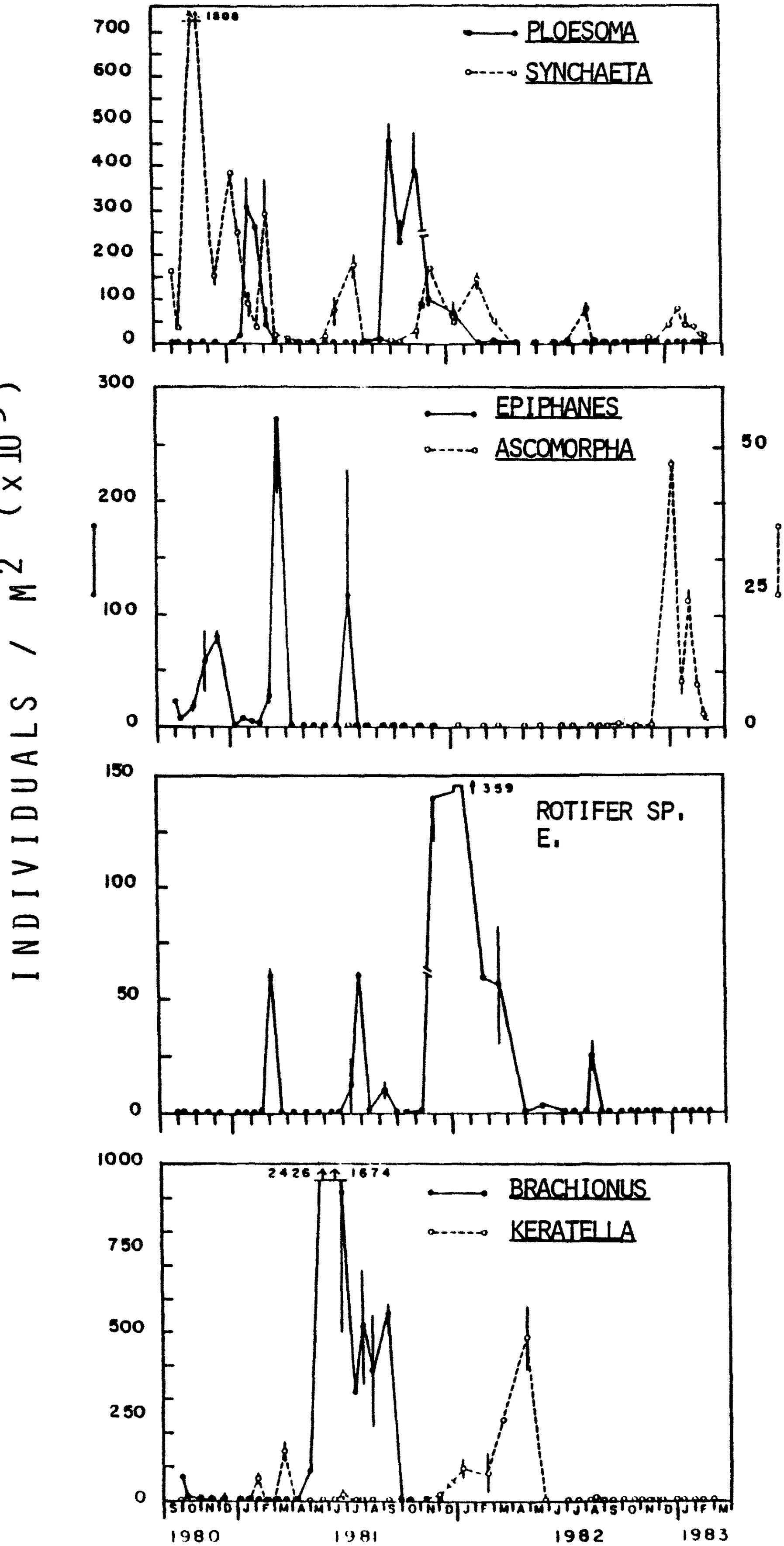


Figure 7.27 (cont.)

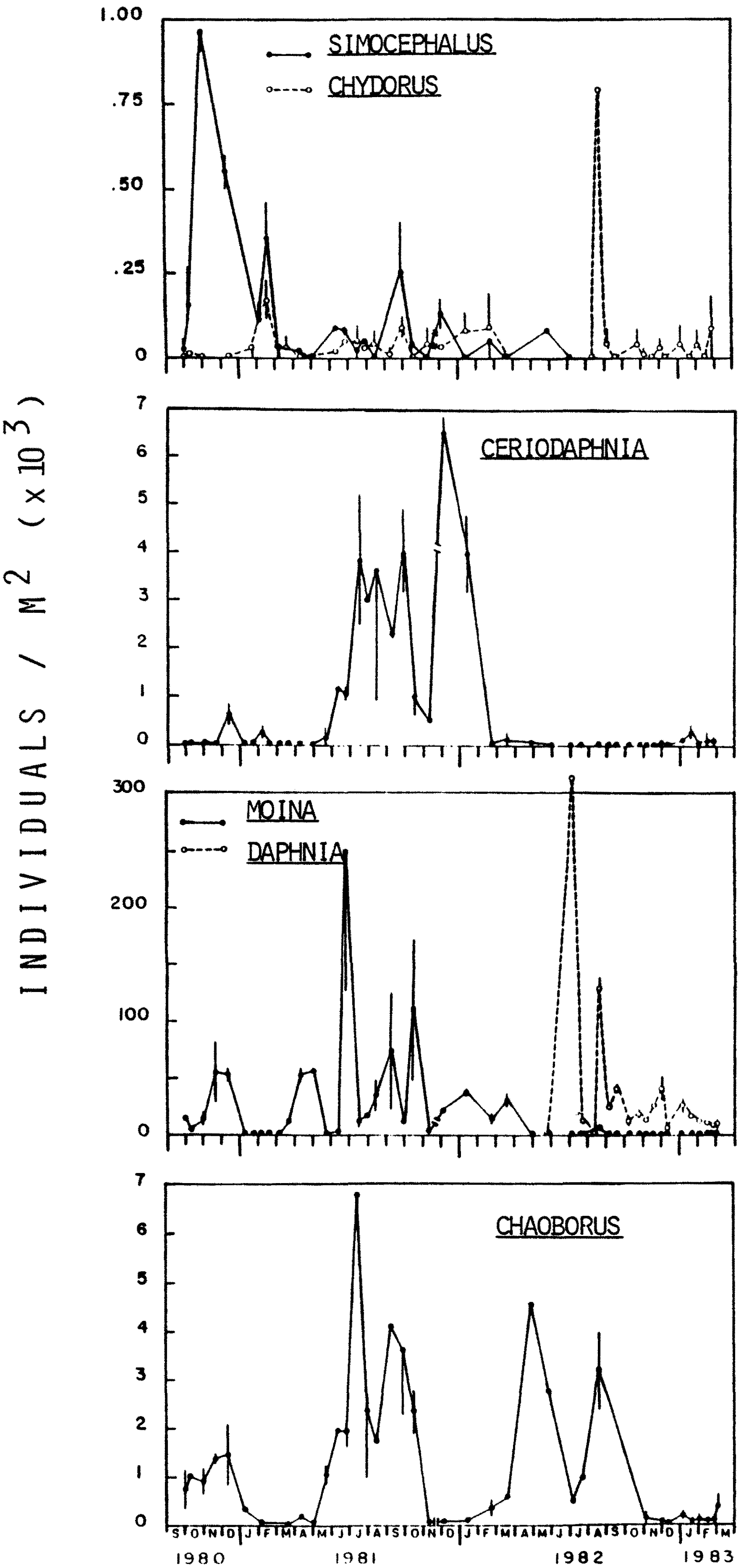


Figure 7.27 (cont.)

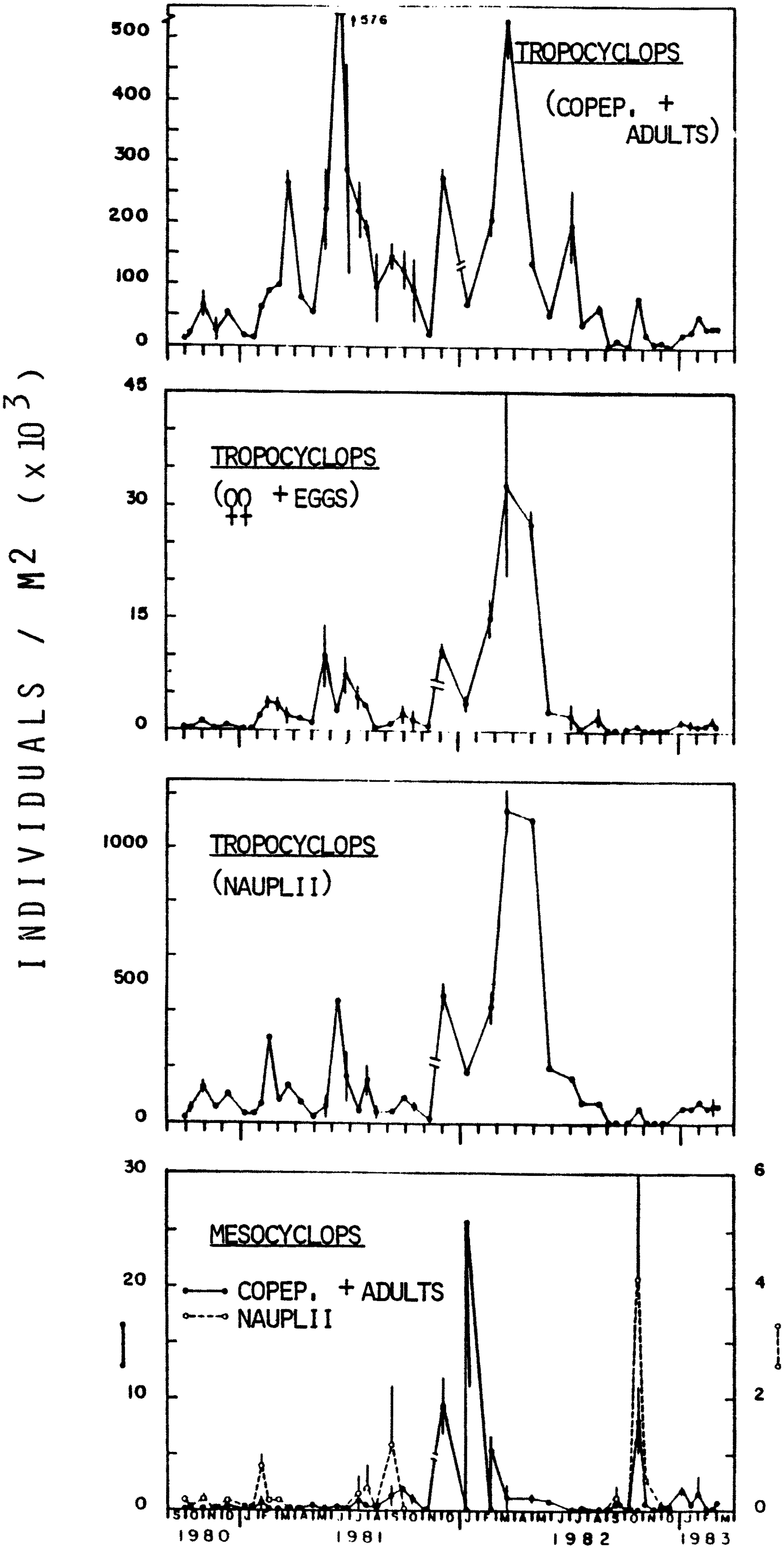


Figure 7.27 (cont.)

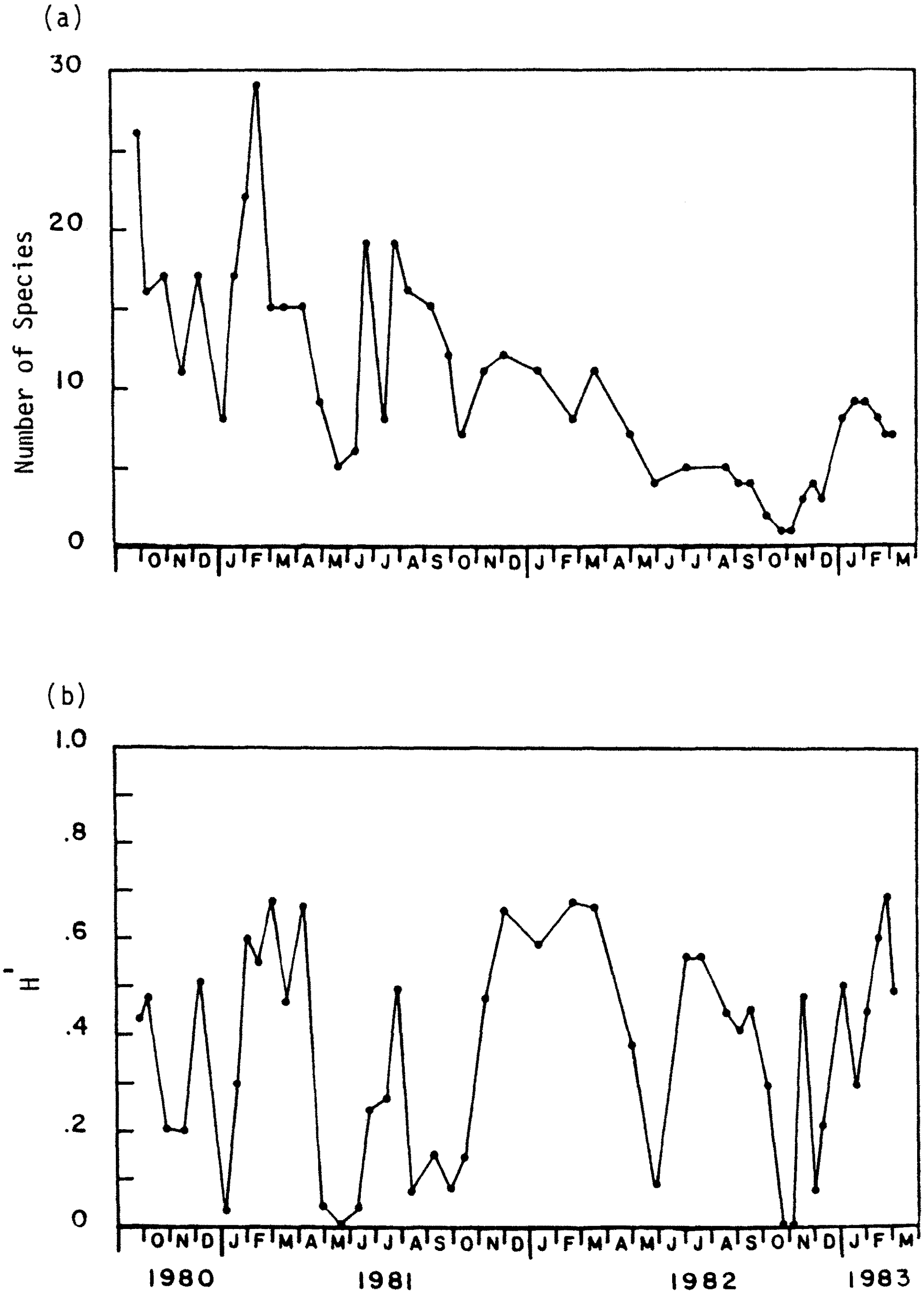
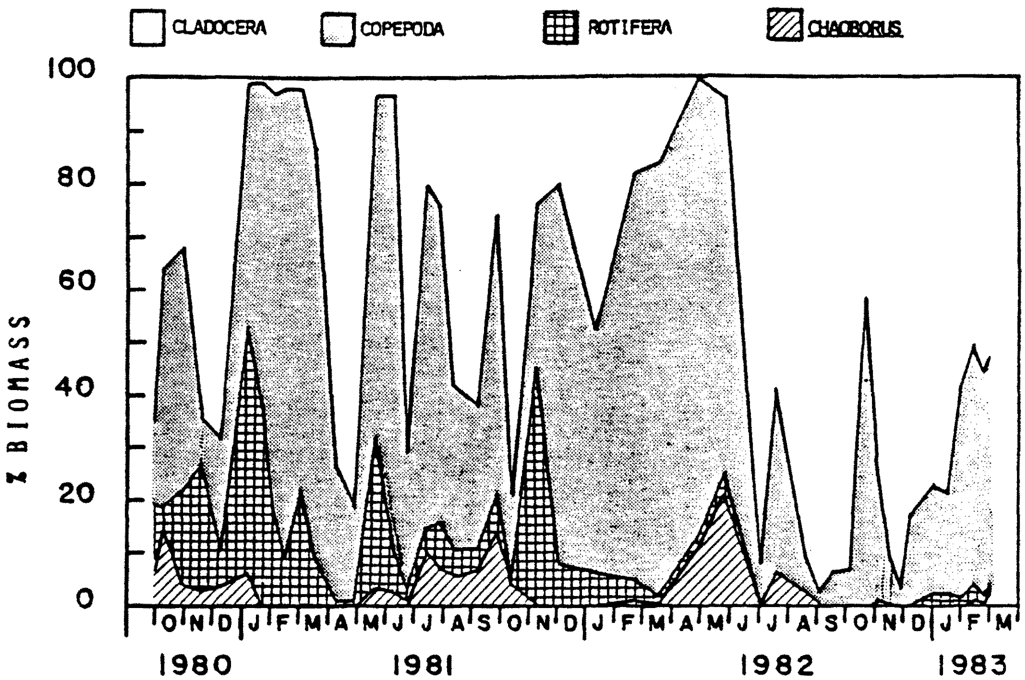


Figure 7.28: Variation in (a) the total number of rotifer species recorded in the plankton samples and (b) rotifer species diversity (H'), L. Yure index station.

Figura 7.28: Varición en (a) número total de especies de rotíferos encontradas en las muestras de plancton y (b) diversidad (H') de especies de rotíferos en la estación índice del L. Yure.

(a)



(b)

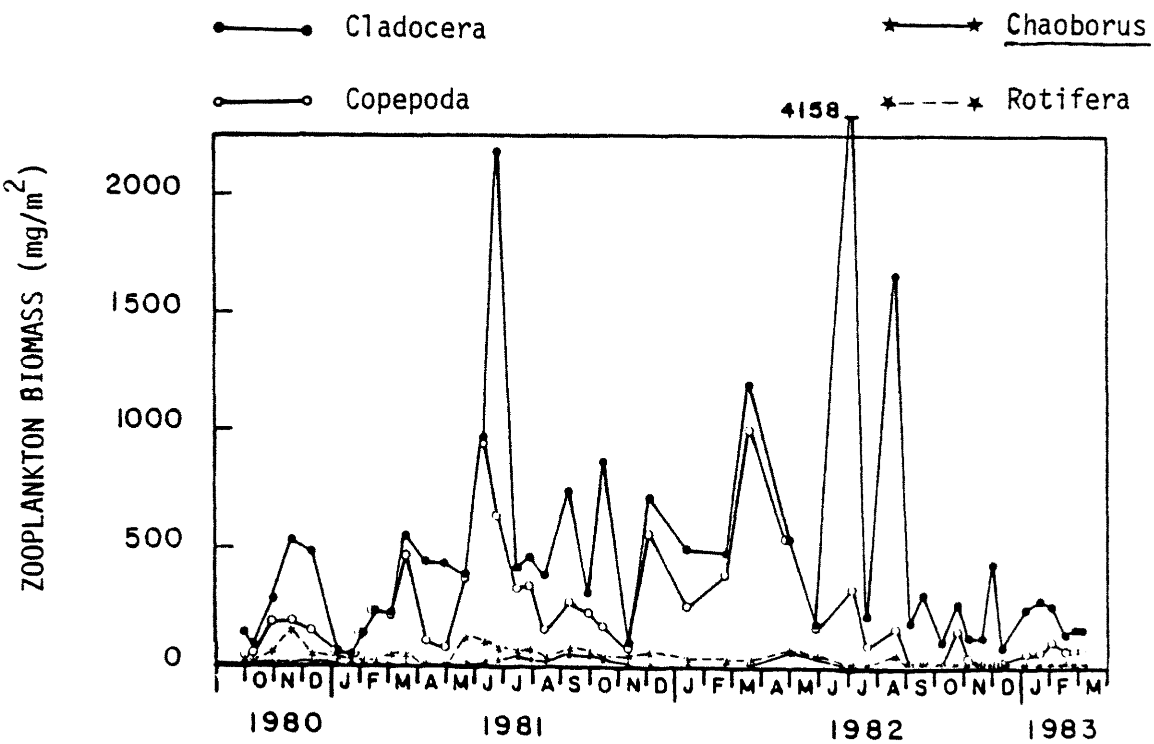


Figure 7.29: (a) Percent of total zooplankton biomass and (b) absolute biomass of major zooplankton groups, L. Yure index station.

Figura 7.29: (a) Porcentaje de la biomasa total y (b) valores de biomasa absolutas de los mayores grupos de zooplancton en la estación índice del L.Yure.

It is convenient to divide the monitoring study into two periods, before and after May 1981, since dramatic changes in the zooplankton community structure started at that time.

7.8.1 Zooplankton Community, Before May 1982

One cladoceran (*Moina micrura*), one cyclopoid copepod (*Tropocyclops prasinus*) and eight rotifer species dominated the zooplankton community, in terms of numbers and biomass, prior to May 1982. Often rotifers were the most numerous organisms but, because of their small size, they usually represented less than 50% of the total zooplankton biomass.

The total number of rotifers fluctuated greatly through the year as various species became dominant. The peak total rotifer density was 2 1/2 million individuals/m^2 on 21/V/81. *Brachionus angularis* comprised over 99% of these individuals. Although a total of 56 rotifer species was recorded from the L. Yure plankton samples, only a few of these were common. Usually between 1 and 5 species represented over 90% of total rotifer numbers. Fig. 7.28a shows the change through time in the total number of species recorded on each sampling date. There was a clear downward trend, especially after July 1981. Rotifer species diversity was calculated using the Shannon-Weiner diversity index, H':

$$H' = - \; p_i \ln(p_i)$$

where p_i = proportion of the total number of individuals represented by species "i" [i.e. the proportional abundance of a species, multiplied by the logarithm of that proportion, is summed over all species.]

H' measures not only the number of species present, but also how uniformly they are represented. Higher values of H' indicate larger species totals and a lack of strong dominance by a few species. (See section 10 for a further illustration of the use of H'). Diversity values for the rotifer community are presented in Fig. 7.28b. No general downward trend in species diversity was observed during the period covered by the monitoring program, even though total densities were decreasing.

Comparison of the patterns of seasonal variation in abundance of the ten most common species (Fig. 7.27) shows that many reached their highest densities during the dry season. *Filinia*, for example, exhibited a bimodal dry season density increase in both 1980/81 and 1981/82. Note that the "trough" between the two peaks occurred in January in each year, the time when the lake was mixing to the bottom. *Hexarthra* densities showed very sharp peaks at the beginning and especially the end of the 1981/1982 dry season, but were very low during the same period the year before.

In contrast to *Hexarthra*, *Polyarthra* and *Brachionus* were abundant over longer periods of time, during the dry and wet seasons respectively. *Brachionus* is typically associated with eutrophic (productive) lakes and it has been suggested that the ratio of the number of *Brachionus* species to the number of *Trichocerca* species may represent a useful index of water quality (Sládecek 1983). (*Trichocerca* is a genus usually found in oligotrophic waters.) This index would not appear to be very applicable with L. Yure, however, since there was a large disparity between the number of species per genus and the total biomass per genus (Appendix 3). Furthermore, *Brachionus* was virtually absent from the lake in 1982 (Fig. 7.27).

Most of the rotifer species encountered in L. Yure are usually herbivorous and feed on phytoplankton cells. The principal carnivorous genera (feeding on other rotifers) were *Asplanchna*, *Ploesoma* and *Trichocerca*. Zooplankton diets were not investigated in detail, however.

The most abundant cladoceran prior to May 1982 was *Moina micrura*. Densities of this species fluctuated greatly through time, without any definite pattern, but with a tendency towards higher values during the wet season.

Ceriodaphnia was fairly common between June 1981 and January 1982 but rare at other times. The midge larva, _Chaoborus_ sp. was most abundant during the wet season, with the peaks being bimodal in both 1981 and 1982.

Because of their very small size, _Tropocyclops_ copepodite and adult stages were not distinguished in the counts. Peak densities occurred at different times in 1981 and 1982 (June and March, respectively). Note, however, that these peak values were similar in both years. Combining copepodites and adults in the counts meant that it was impossible to use cohort analysis to estimate copepod growth rates and production (see section 11 for a description of cohort analysis with reference to fish growth rates). This method, however, would represent a most useful approach in future, more detailed, studies of secondary production in the El Cajón reservoir.

The peak number of _Tropocyclops_ females carrying eggs in 1982 was approximately 4 X that in 1981, even though densities of copepodites + adults were similar in both years. This strongly suggests (although does not prove, since the actual total number of adult females on each date was unknown) that the proportion of reproductive females increased from 1981 to 1982. Although there appears to be a correlation between this pattern and increased levels of primary production observed in the 1982 dry season (Fig. 7.23), there is no real evidence of cause and effect.

Mesocyclops leuckartii is a larger species of carnivorous cyclopoid copepod than the herbivorous _Tropocyclops_ and is often associated with the benthos, although in some lakes it represents a major component of the plankton (for example, the Kainji reservoir in Nigeria, Clarke 1978). A few individuals were recorded in most of the samples taken at the L. Yure index station. Densities were highest between November and March but even at this time they represented <10% of _Tropocyclops_ numbers (except for October 1981).

7.8.2 Zooplankton community, after May 1982

At the end of May 1982, the large cladoceran *Daphnia pulex* was first recorded in L. Yure. This species was the dominant zooplankter in L. de Yojoa at that time. By the beginning of July, it had reached a density of over 300,000 individuals/m^2. After this time, the population fluctuated about a gradually decreasing mean.

The appearance of *Daphnia* was associated with some dramatic changes in the rest of the zooplankton community, which are apparent from inspection of Fig. 7.27. Total rotifer density decreased from about 1.3×10^6 to less than 0.1×10^6 individuals/m^2 during the period May - June 1981. It is interesting to note that rotifer numbers were already low by 27/V/82, the date when *Daphnia* was first recorded, but itself still at low densities. Furthermore, during 1981, rotifer densities had also dropped sharply at nearly the same time of year (June/July), but they later recovered. Thus, it appears that the decrease in rotifer densities preceded the development of a large *Daphnia* population, and that the latter was subsequently associated with a failure of the rotifer populations to re-establish themselves. The rotifer species most obviously undergoing rapid population declines around May 1982 were *Hexarthra*, *Polyarthra*, Rotifer sp. E, and *Keratella cochlearis*. Only one species, *Ascomorpha* sp., became abundant between May 1982 and March 1983. This species had not been previously recorded from L. Yure.

There were also very significant changes within the cladoceran community which were associated with the appearance of *Daphnia*. The previously dominant cladoceran, *Moina*, became very rare, for example. Note that *Moina* densities had also decreased sharply in May 1981, but subsequently increased again. In 1982, the population declined during April (before *Daphnia* appeared) but they failed to recover later on. The similarity between the graph of *Moina* densities in 1981 and that of *Moina* + *Daphnia* in 1982 is very interesting (Fig. 7.27).

Simocephalus and *Ceriodaphnia* are other cladocerans which were rarer after the appearance of *Daphnia* than before. Note that the record for *Ceriodaphnia* is a further example of a species declining in density before the *Daphnia* invasion and subsequently failing to recover, rather than exhibiting a sharp decline at the same time that *Daphnia* was increasing.

Tropocyclops densities initially increased (relative to the two previous dates) following the invasion of *Daphnia*, but later declined to pre-1980 levels.

Changes in the relative distribution of biomass between the various components of the zooplankton community are summarized in Fig. 7.29a. *Daphnia* represented the major component of total biomass between June and December 1982, whereas copepods had generally been most important during the previous nine months. It is interesting to note, however, that during the first two months of 1982, when zooplankton densities in general were low, copepods again represented about 50% of the total biomass.

Fig. 7.29b is an alternative presentation of the data, showing variation through time in the absolute biomass values of the four major zooplankton groups. Total zooplankton biomass was on average higher between June 1981 and June 1982 than at other times. After the peak in *Daphnia* densities had passed in September 1982, total biomass was no greater than before the appearance of this cladoceran species. However, it should be noted that zooplankton biomass effectively available as food to fish continued to be greater after May 1982 than before, because *Daphnia* represented a much more visable/easily captured prey species than did the other zooplankters.

Total biomass tended to be highest towards the end of the dry season, although seasonal variation in this parameter was not very consistent between years. Algal primary production and epilimnetic temperatures were also highest at this time of year. A more detailed study of zooplankton secondary production, however, is needed to adequately evaluate the relationship between phytoplankton and zooplankton communities. The fact that Daphnia invaded the lake at a time when primary production had been considerably higher than in previous years may or may not have been a coincidence. There were no obvious shifts in phytoplankton species composition at this time and so the reason for the dramatic changes in the zooplankton community must remain unanswered. It should be noted, however, that the cladoceran community of L. de Yojoa also underwent significant changes in relative species abundance during the period of this study, even though the actual species composition did not change (see section 8). Temporal variation in zooplankton communities will be further discussed in section 9.

7.8.3 Zooplankton synoptic studies

Zooplankton were occasionally sampled at a number of different stations in the lake in order to obtain some estimate of spatial hererogeneity. Data from two sampling dates are presented in Table A3.4 (Appendix 3), and are summarized in Fig. 7.30. (Note that only the most abundant rotifer species were counted on 31/VII/80.) Results are expressed on an areal basis (individuals/m^2) and the shallow depth of some sampling stations may have influenced the number of organisms collected.

The between-station variation in both absolute and relative densities of the major groups is clearly seen in Fig. 7.30. Not surprisingly, patterns of variation were dissimilar on both sampling dates. Horizontal variation was also not uniform within the major groups. For example, on 30/IX/80, Synchaeta was most abundant at stations 4 and 5, whereas Epiphanes, Filinia and Keratella were most common at the stations near the inflow of Q. Tepemechín (Appendix 3).

A number of factors potentially influence the horizontal distribution of zooplankton, for example phytoplankton biomass and productivity, the density of

(a)

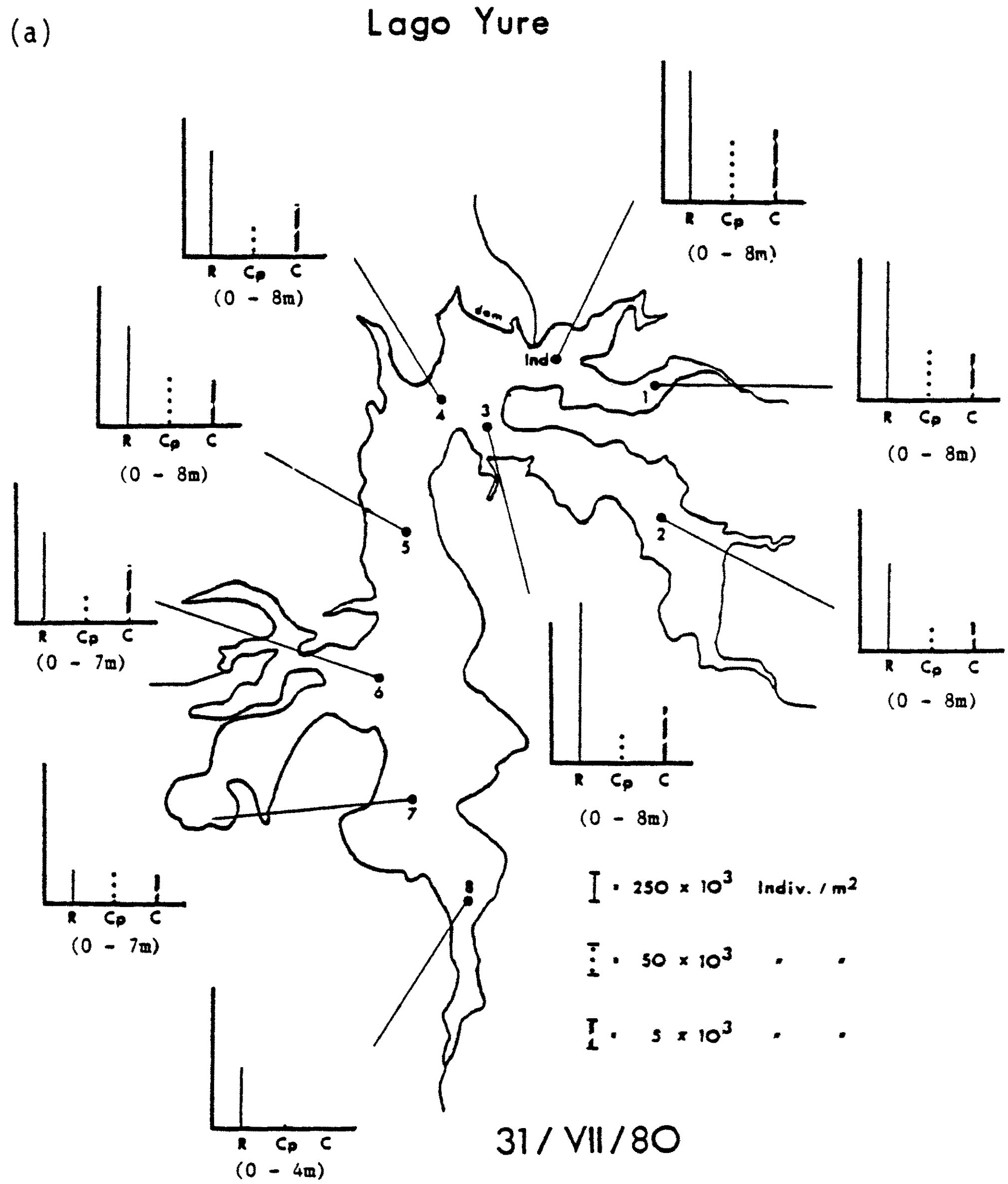


Figure 7.30: Synoptic zooplankton densities, L. Yure
(a) 31/VII/80
(b) 30/IX/80

Figura 7.30: Densidades en el sinóptico del zooplancton en el L. Yure
(a) Fecha del 31/VII/80
(b) Fecha del 30/IX/80

(b)

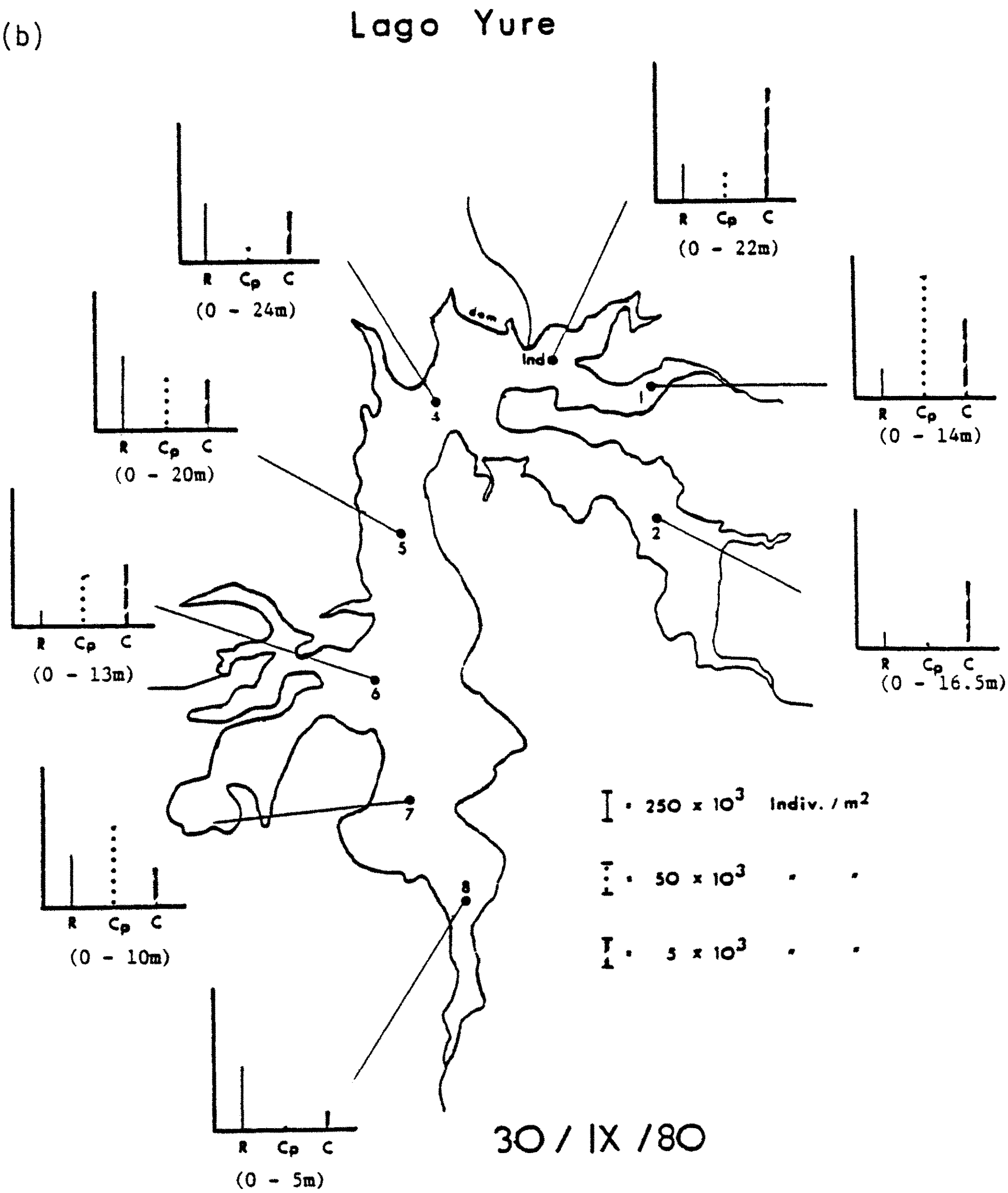


Figure 7.30 (cont.)

predators and wind-induced water movements (Hart 1978). An intensive study would be required to fully investigate the relative importance of each of these and other factors. The existing data base does not allow any causative explanation to be put forward for the spatial heterogeneity in the Yure zooplankton community.

7.8.4 Depth distribution

A systematic study of the depth distribution of zooplankton in L. Yure was not included in the present program. However, a few discrete-depth sample series were collected in 1980 and, subsequently, two of the biologists working with the program undertook more detailed studies for their own dissertation research.

One series of depth profiles is presented here, from 30/IX/80. The samples were collected every meter through the water column at a station near the normal QT sampling location. The maximum depth at this station was only 10 m, but oxygen depletion was significant below 5 m.

The inverse relationship between copepod (*Tropocyclos prasinus*) and rotifer densities is obvious from Fig. 7.31. *Epiphanes*, *Keratella*, *Brachionus* and the Cladocera were found primarily in the oxygenated zone, whereas most of the copepods were deeper in conditions of low oxygen and light. Diurnal variation in zooplankton depth distribution needs to be further studied in L. Yure, since it relates to the degree to which the organisms are available as food to fish.

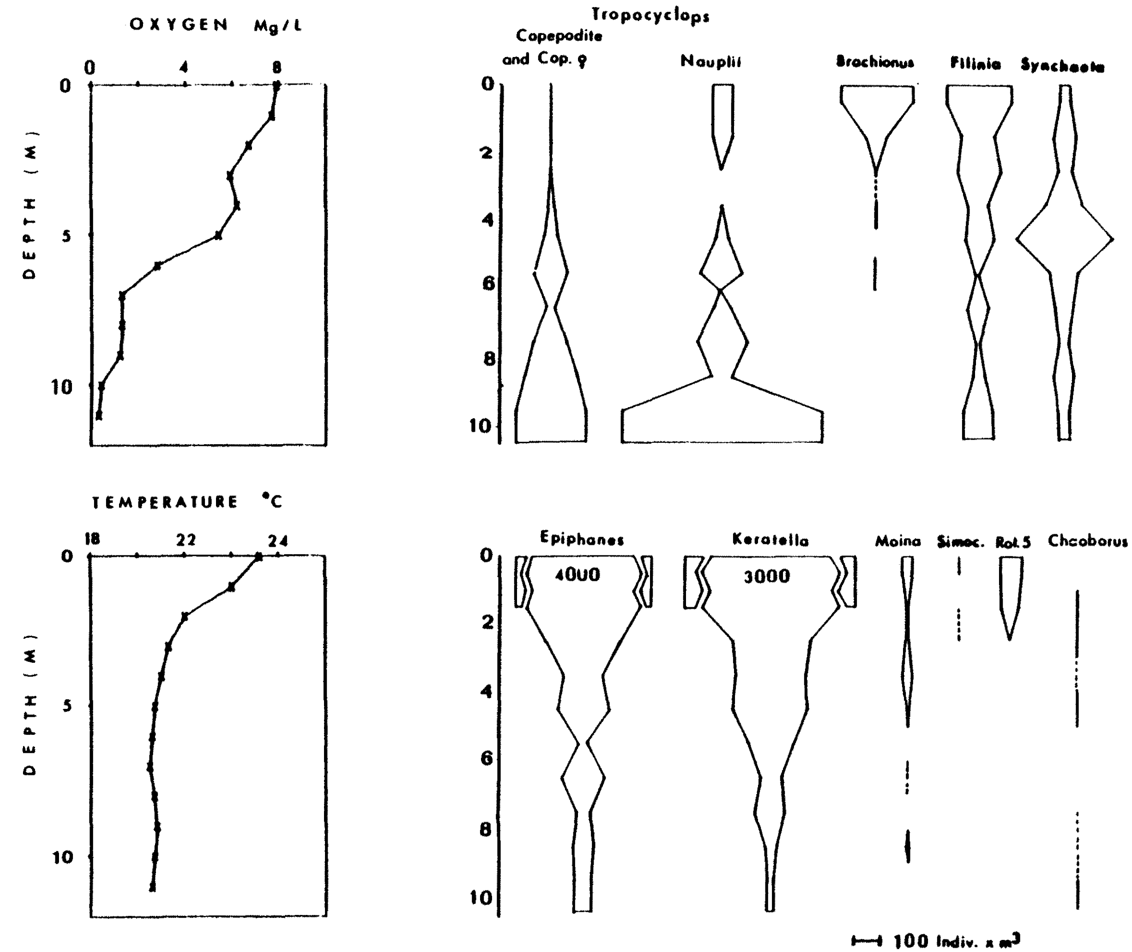


Figure 7.31: Depth distribution of zooplankton in L. Yure, at a station near QT, 30/IX/80.

Figura 7.31: Distribución por profundidad de zooplancton en una estación cerca de QT en el L. Yure, 30/IX/80.

8 LAGO DE YOJOA

8.1 INTRODUCTION

Lago de Yojoa is the largest natural lake in Honduras, with a surface area similar to that of the future El Cajón reservoir. Table 7.1 presents the morphological characteristics of this lake, and Fig. 8.1 shows the location of the principal sampling station used in the study.

The eastern shoreline of the lake is gently sloping while that to the west is much steeper (see plate 8.L). Rooted and floating macrophytes are present around almost the entire circumference of the lake. These aquatic plant beds are especially dense along the eastern shore. Highest densities are usually found between depths of 0-4 m, but some species, e.g. *Vallisneria americana*, extend down to 8 m. The most common genera are *Vallisneria*, *Panicum*, *Typha*, *Potamogeton* and the macro-alga *Chara* (Cruz and Delgado 1980).

A forested area at the southern end of the lake, flooded as a result of the project increasing the generating capacity of the Cañaveral/Río Lindo hydroelectric complex, is now infested with the water hyacinth *Eichhornia crassipes* (see plate 8.M). This infestation at times obstructs the channel bringing water from the Varsovia river to L. de Yojoa and was the subject of a study by the laboratory.

Floating plant mats (sudds) often break off from the beds of littoral vegetation when the lake level is rising and are then blown by the prevailing north-south winds towards the forested area at the southern end of the lake (see plate 8.N). The largest sudd observed during the period of this study was between 70 and 100 m in length.

Cruz and Delgado (1980) have provided a good description of the macrophyte communities of L. de Yojoa. The littoral (shoreline) area was not a focus of the present study and will not be further considered here.

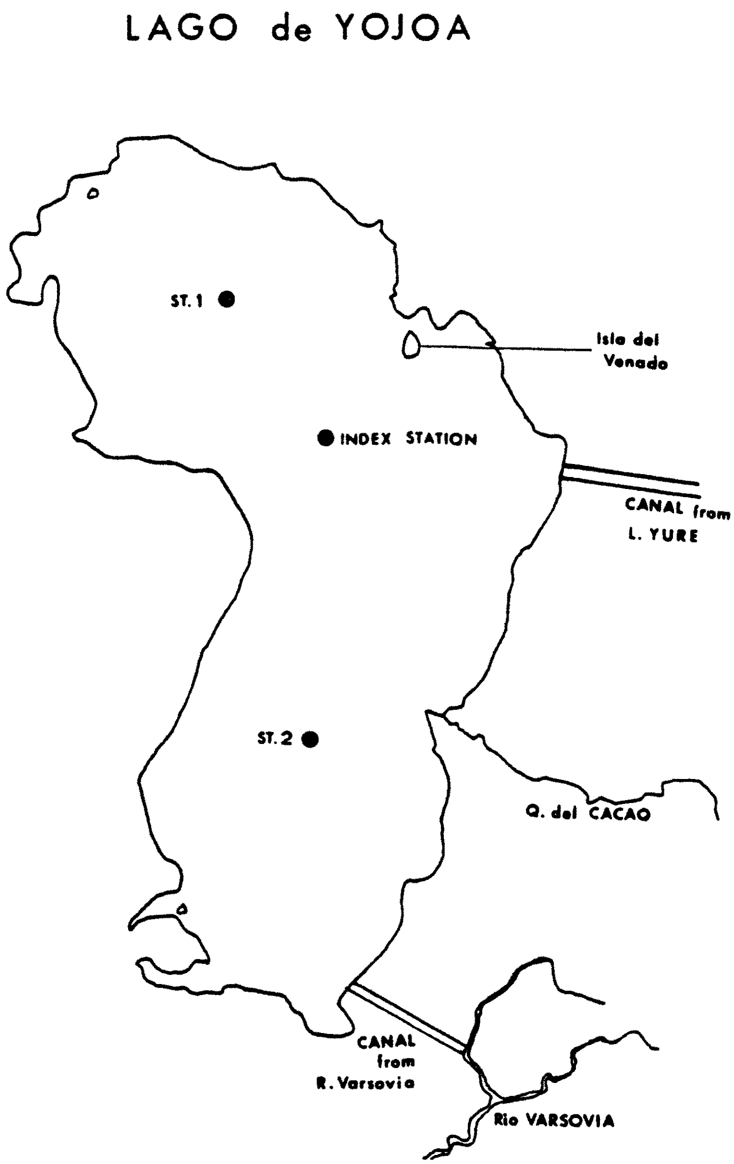


Figure 8.1: Map of L. de Yojoa, showing sampling stations.

Figura 8.1: Mapa del L. de Yojoa senalando las estaciones de muestreo.

Plate 8.L. Lago de Yojoa, a view of the northeast end of the lake.
Foto 8.L. Lago de Yojoa, vista noreste del lago.

Plate 8.M. Eichornia at southern end of lago de Yojoa.
Foto 8.M. Eichornia al extremo sur del lago de Yojoa.

Plate 8.N. Lago de Yojoa, looking towards southern end. Note "sudd".

Foto 8.N. Lago de Yojoa, mirando hacia el extreno sur. Nótese parte del litoral flotando.

The natural watershed of Lago de Yojoa is relatively small (337 km^2, Cruz and Delgado 1980), but has effectively been increased since 1978 through the diversion of the Yure and Varsovia rivers. The effects of these diversion projects on the ecology of the lake are unknown, since almost no pre-diversion base-line data exist.

Although the ecology and limnology of L. de Yojoa are of much interest in themselves, and potentially of great value in terms of the management of the lake's water quality and fishery, the work carried out during the present study was undertaken principally to provide detailed knowledge of endemic and exotic lake flora and fauna as well as to provide a limnological comparison with L. Yure. Every lake system is to some extent different. The more comparative information that is available on lakes from a similar geographic and climatic area, the greater the potential is for predictive limnology to play a useful role in the solution of water-related problems.

In this section, results of the limnological studies carried out on L. de Yojoa are presented and analyzed. This is done in a more condensed form than was the case for the L. Yure data, because introductory discussions for each of the parameters do not need to be repeated from section 7. Section 9 integrates data from L. de Yojoa within the framework of a discussion of the Yure and El Cajón reservoirs.

8.2 PHYSICAL LIMNOLOGY

8.2.1 Thermal Regime

The thermal regime of L. de Yojoa is shown in Figs. 8.2 and 8.3. Appendix 10 contains the entire record of temperature data. As was the case with L. Yure, stratification patterns are distinguished more easily by oxygen concentrations than by temperature profiles, although temperature is the primary

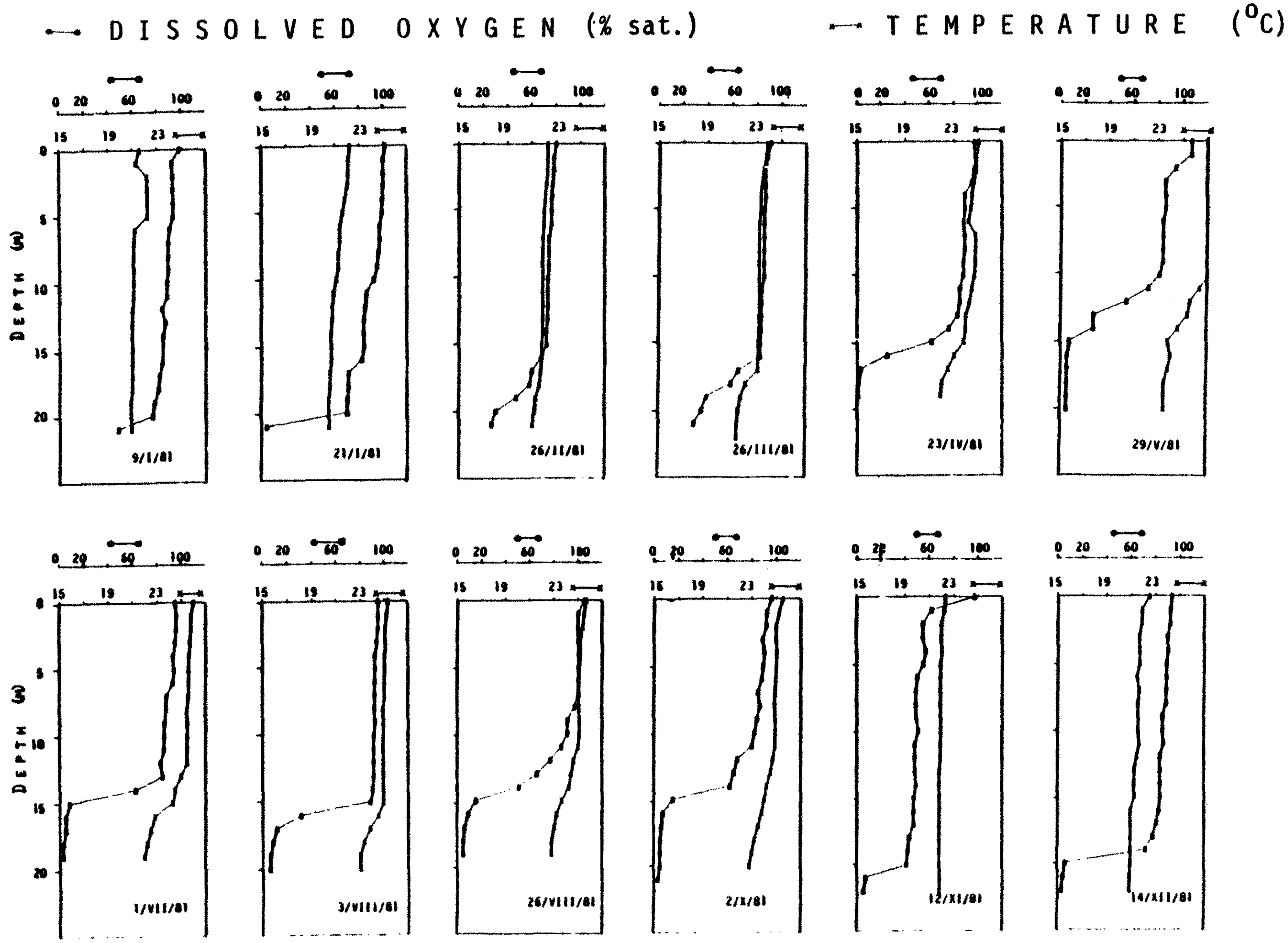


Figure 8.2: Depth profiles of temperature and oxygen, L. de Yojoa.

Figura 8.2: Perfiles de profundidad de temperatura y oxígeno en el L. de Yojoa.

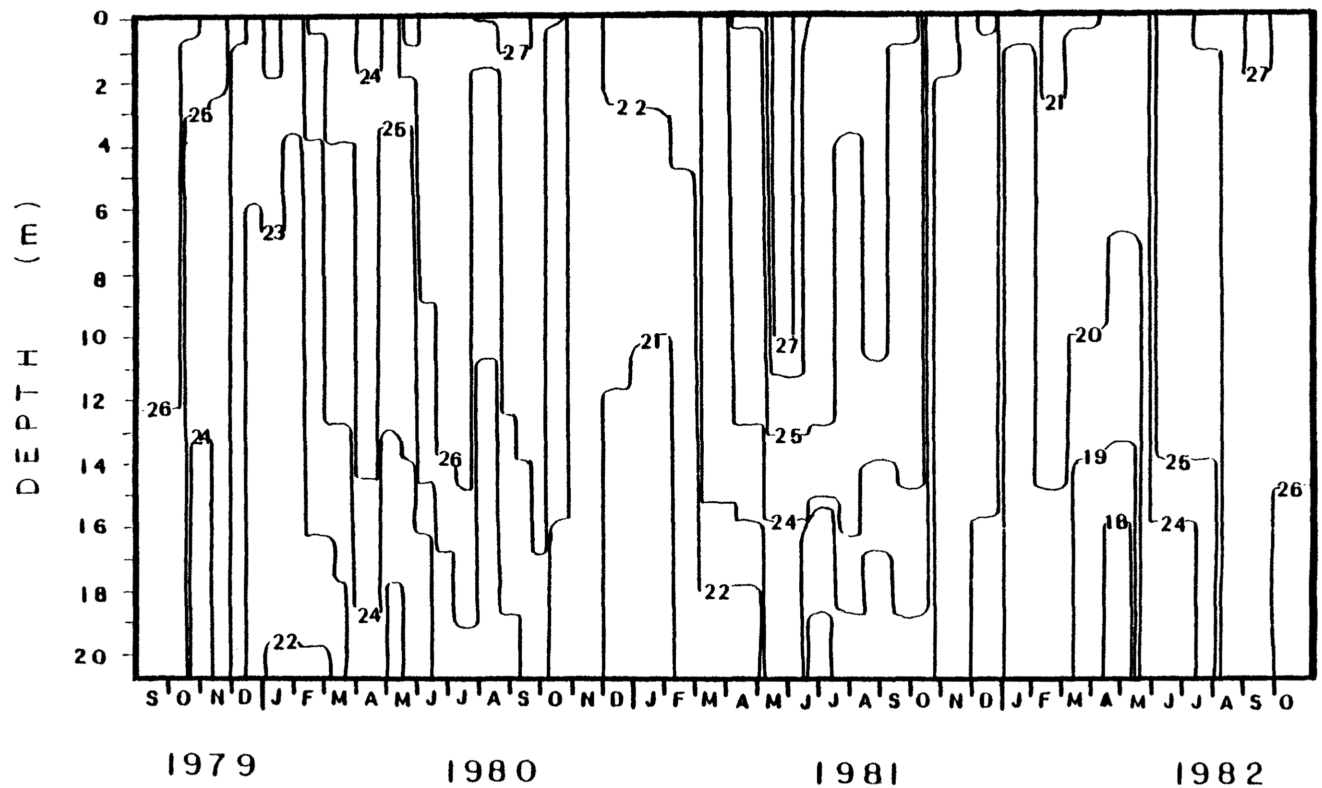


Figure 8.3: Depth-time diagram of isotherms, L. de Yojoa.

Figura 8.3: Diagrama profundidad-tiempo de isotérmicas en el L. de Yojoa.

factor affecting stratification. The lake mixed to the bottom during November, December and part of January and thus is apparently monomictic. However, some of the water chemistry data (see below), in addition to the temperature and oxygen profiles, indicated that complete mixing may also occur at times during the wet season. For example, the temperature/oxygen profiles on 24/VII/80 and 14/VIII/80 (Appendix 10) show an eroded, or lowered, thermocline. The hypolimnetic phosphorus and iron concentrations (Table 8.3) suggest that at some time close to the sampling dates oxygen had been re-introduced into the deepest waters, i.e. the lake had mixed completely. If this was so, then the lake can be properly classified as dimictic, that is, it mixes to the bottom during two periods in the year.

Stratification was usually established in late January or February, with the thermocline rising to 13-15 m by the beginning of the wet season. Daily winds (strongest in the afternoons) kept the epilimnion well mixed and generally prevented shallow, temporary thermoclines from developing as they often did in L. Yure.

Anomalous temperature profiles were occasionally observed (e.g. 9/I/81 and 23/IV/81, Fig. 8.2) in which subsurface water was slightly warmer than surface water. The cooler surface layer may have represented water that had lost heat to the atmosphere during the night and was in the process of sinking, but had not been mixed into the lower layers of the epilimnion because of very calm conditions.

Surface temperatures ranged from about 21.5^{o}C in January to about 27.5^{o}C in May/June. Bottom temperatures ranged from about 20^{o}C to 22^{o}C. Thus the temperature difference between surface and bottom, even under stratified conditions was a maximum of about 5^{o}C and often much less. This was mainly because of the "open" morphology of the lake basin, providing a long fetch for the prevailing north-south winds. Density gradients through the water column were therefore lower in L. de Yojoa than in L. Yure, resulting in a less stable stratification in the former lake.

8.2.2 Light Penetration

Secchi depth was usually between about 4 and 10m (Fig. 8.7). Highest values (clearest water) were generally observed between October and January, but seasonal variation was not very distinct. The greatest Secchi depths were both recorded in November; on each occasion turnover had recently occurred.

The lack of distinct seasonal variation in water clarity was emphasized by the extinction coefficients. These are summarized in Table 8.1 and Fig. 7.11. Average water column values ranged from 0.21 to 0.52 m^{-1}. Note that coefficients calculated for the bottom few meters of the water column were often much higher than those for the overlying water. There are two possible explanations for this; first, that the high values were caused by the disturbance of bottom sediments or, second, that photometer sensitivity was significantly different at very low light levels. In either case, extinction coefficients calculated over the upper 10-15 m of the water column represent the important values. A series of light profiles are presented in Fig. 8.6. The arrow on each profile indicates the depth at which 1% surface light was present. The euphotic zone in L. de Yojoa, therefore, was usually 11-14 m deep.

Turbidity values, corresponding to the high transparency of the water, were always uniformly low throughout the water column and generally ranged from 0.5 - 1.5 NTU.

8.2.3 Conductivity

Conductivity usually ranged from about 160 µmho/cm at the surface, to about 180-190 µmho/cm at the bottom (Appendix 10). The conductivity gradient with depth was steeper in anoxic, or low-oxygen hypolimnetic water, because ions were

Table 8.1: Extinction coefficients, L. de Yojoa, (m^{-1})

Tabla 8.1: Coeficientes de extinción en el L. de Yojoa, (m^{-1}).

Date	Depth	n	
20/III/80	1-17	.26	
	17-20	.96	
1/V/80	1-14	.25	
	15-17	.44	
22/V/80	1-13	.23	
	14-17	.56	
12/VI/80	1-13	.27	
	13-15	.63	
3/VII/80	1-14	.23	
	14-17	.39	
24/VII/80	1-14	.24	
	14-17	.43	
14/VIII/80	1-7	.32	
4/IX/80	1-16	.39	
25/IX/80	1-17	.40	
	18-20	.71	
29/X/80	1-16	.30	
12/XI/80	1-14	.25	
27/XI/80	1-17	.31	
18/XII/80	1-12	.52	
9/I/81	1-19	.36	
29/I/81	2-10	.21	
	10-15	.40	$\bar{n}$ = .33
	16-20	.63	
26/II/81	1-15	.31	
	15-18	.48	
26/III/81	1-13	.35	
	14-18	.47	
23/IV/81	1-12	.31	
29/V/81	1-14	.33	
1/VII/81	1-13	.27	
	14-16	.89	
3/VII/81	1-15	.29	
26/VII/81	1-15	.27	
	10-15	.35	
2/X/81	1-15	.29	
13/XI/81	1-13	.31	
14/XII/81	1-12	.35	
19/I/82	1-10	.40	
24/II/82	1-15	.28	
23/III/82	1-4	.38	$\bar{n}$ = .31
	5-12	.29	
27/IV/82	1-12	.35	
20/V/82	1-10	.42	
28/VI/82	1-12	.34	
19/VII/82	1-12	.34	
24/VIII/82	1-12	.34	
5/X/82	1-16	.27	
	16-19	.49	

released from the sediments when the protective layer of ferric iron was reduced to ferrous iron (see sections 7.4.3 and 7.4.5).

3. WATER CHEMISTRY

8.3.1 Alkalinity and pH

Alkalinity and pH data are summarized in Table 8.2. Alkalinity of the epilimnion was usually in the range 60-75 mg/l as $CaCO_3$, with values being lower in the wet season than in the dry. Hypolimnetic alkalinities were nearly always very similar to epilimnetic values. Mean epilimnetic pH was 7.4 while hypolimnetic values averaged 6.9. The pH of the bottom water was predictably lower under conditions of stratification. Differences in the pH of surface and bottom water presumably resulted both from microbial decomposition processes in the hypolimnion and photosynthetic utilization of inorganic carbon in the euphotic zone.

8.3.2 Oxygen

Hypolimnetic oxygen concentrations were reduced shortly after stratification was established in January or February, and by the end of March or April the hypolimnion was anoxic (Figs. 8.2 and 8.4). Oxygen was reintroduced into deeper water during the wet season, whenever storms drove the thermocline downward.

The influence of turnover on water column oxygen concentrations is well illustrated in Fig. 8.2 by the profile for 12/XI/81. Mixing to the bottom had occurred shortly before this sampling date, bringing anoxic water from below 15 m (see profile for 2/X/81) to the surface. This resulted in most of the water column being less than 60% saturated with oxygen. Presumably within a short time and certainly by the following sampling date however, oxygen

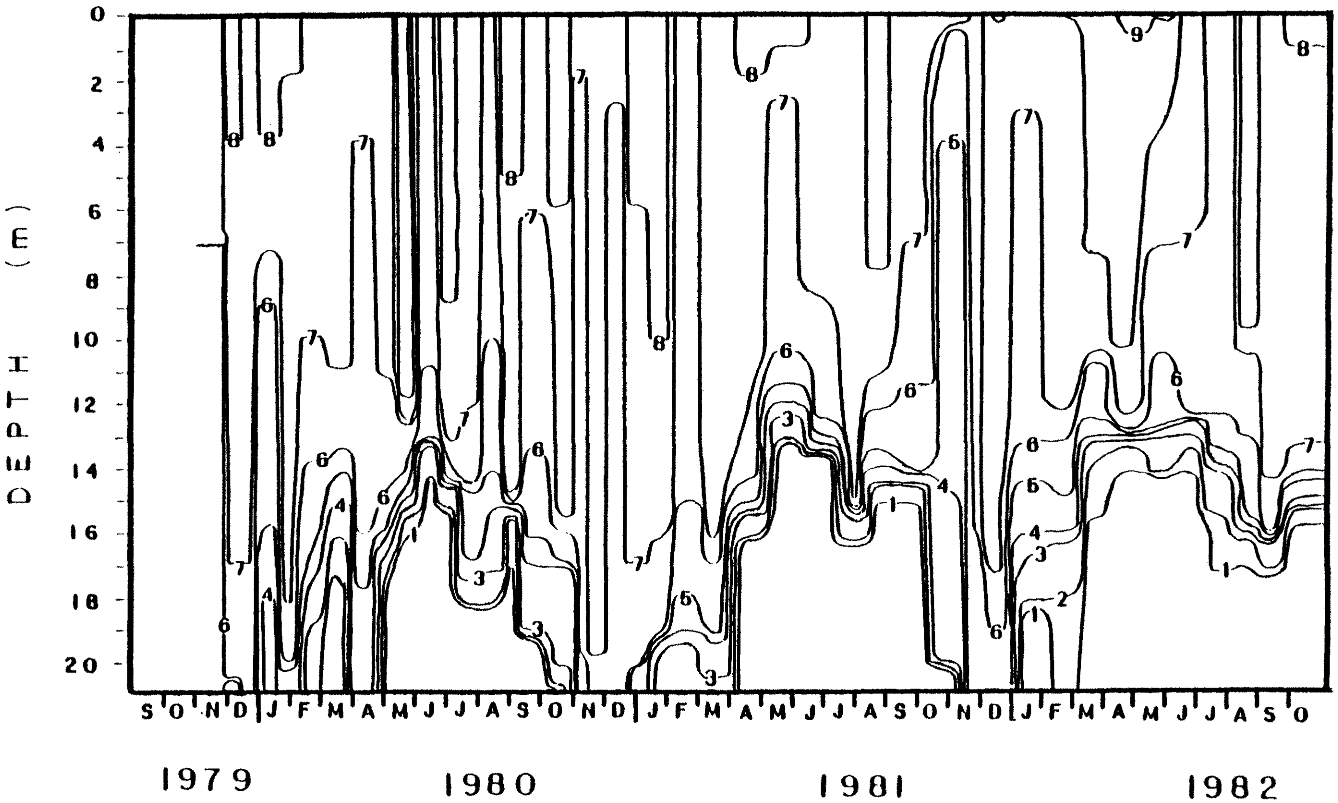


Figure 8.4: Depth-time diagram of oxygen isopleths, L. de Yojoa.

Figura 8.4: Diagrama profundidad-tiempo de cotas de oxígeno en el L. de Yojoa.

Table 8.2: Alkalinity and pH , L. de Yojoa.

Tabla 8.2: Alcalinidad y pH en la estación índice del L. de Yojoa.

Date	Depth*	pH	Alkalinity (mg/l $CaCO_3$)	Date	Depth*	pH	Alkalinity (mg/l $CaCO_3$)
1981				1982			
9/I	E	7.6	74.2	19/I	E	7.0	73.0
	H	7.6	72.8		H	7.0	71.0
29/I	E	7.8	71.5	24/II	E	7.2	75.0
	H	6.8	67.4		H	6.9	74.5
26/II	E	8.0	68.8	23/III	E	6.2	73.0
	H	7.3	67.3		H	6.0	72.5
26/III	E	7.7	73.5	27/IV	E	7.0	75.0
	H	7.1	73.8		H	6.7	79.2
29/V	E	7.7	53.5	20/V	E	7.6	73.3
	H	6.6	65.5		H	6.8	73.0
1/VII	E	7.6	59.9	28/VI	E	8.0	69.8
	H	6.9	71.2		H	7.9	71.0
3/VIII	E	8.4	61.4	19/VII	E	7.0	70.0
	H	7.7	65.8		H	6.3	83.0
26/VIII	E	7.2	64.2	24/VIII	E	7.1	70.0
	H	6.6	71.4		H	6.9	71.2
2/X	E	7.4	68.7	5/X	E	7.6	68.0
	H	6.3	79.5		H	6.7	76.0
13/XI	E	7.4	76.5	8/XI	E	7.4	67.0
	H	7.2	75.8		H	7.2	68.0
14/XII	E	7.0	68.2				
	H	6.6	67.5				

* E = epilimnion (usually about 0-15 m; 0-15 m when isothermal)
H = hypolimnion (1 m above bottom)

concentrations had again risen to about 100% saturation. The influence of this mixing event was also observed with nutrient concentrations (see below).

8.3.3 Phosphorus

Phosphorus data are summarized in Fig. 8.5 and Table 8.3. PO_4-P concentrations were always low (<5 µg/l) in the epilimnion and usually low in the hypolimnion, even when bottom water was anoxic. Hypolimnetic concentrations were higher however, on a few sampling dates, e.g. April-October 1982. These data suggest that the hypolimnion was anoxic for a longer period of time in 1982 than in the two previous years. This led to an increased hypolimnetic accumulation of PO_4-P, representing release both from the sediments and from decomposing organic matter.

Epilimnetic concentrations of total phosphorus (TP) also were often low, averaging 10 µg/l. However, concentrations were higher between April and November 1981 and at the beginning of the 1982 wet season. At these times most of the TP was present as particulate phosphorus (and presumably soluble unreactive phosphorus; see section 6.2.7). This fraction probably represented phosphorus incorporated into algal cells, since inorganic sediment concentrations in the upper part of the water column were low. Turbid inflows to the lake are infrequent and the presence of macrophyte beds around the shoreline probably remove a significant proportion of the total phosphorus which does enter *via* the tributaries. It is important to note, however, that primary productivity data do not support the hypothesis that the higher TP levels are caused by algal phosphorus. The high TP concentration on 28/VI/82 may have resulted from contamination or, more probably, an accidental reversal of epilimnetic and hypolimnetic samples. The average epilimnetic phosphorus concentration that appears in Table 9.1 has been calculated without this datum.

Hypolimnetic concentrations of TP had a mean value of 22 µg/l, but ranged

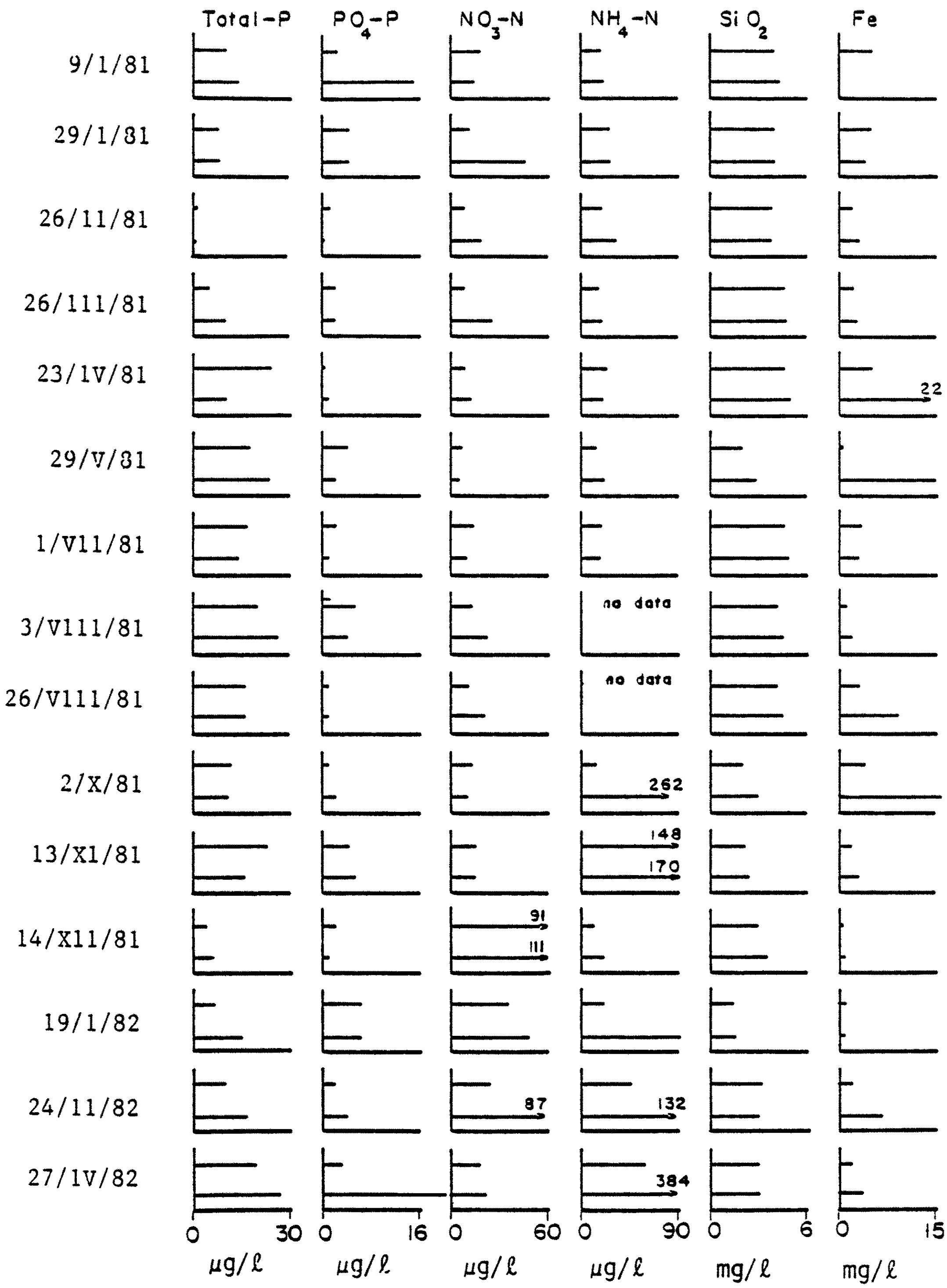


Figure 8.5: Seasonal variation in nutrient concentrations, L. de Yojoa. (The upper bar on each graph represents mean epilimnetic concentration, the lower bar represents the concentration 1m above the sediments).

Figura 8.5: Variación estacional en las concentraciones de nutrientes en el L. de Yojoa. (La línea superior en cada gráfica representa la concentración epilimnética, la línea inferior representa la concentración a una profundidad de un metro arriba de los sedimentos).

Table 8.3: Nutrient concentrations, L. de Yojoa.

Tabla 8.3: Concentraciones de nutrientes en L. de Yojoa.

Date	Depth (m)	Total-P (µg/l)	PO_4-P (µg/l)	NO_3-N (µg/l)	NH_4-N (µg/l)	SiO_2 (mg/l)	Fe (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)
28/IX/79	E	10	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-
8/X/79	E	10	-	-	14	2.6	0.02	1.6	27.3	2.6	1.2
	H	110	-	-	632	5.2	0.72	1.8	28.2	2.8	1.4
31/X/79	E	16	-	-	7	3.8	0.02	1.6	27.4	2.1	1.2
	H	125	-	-	252	4.8	0.19	1.7	28.4	2.1	1.3
21/XI/79	E	7	-	-	10	5.0	< 0.01	1.6	27.0	2.2	1.2
	H	26	-	-	152	4.6	0.01	1.6	27.0	2.2	1.3
6/XII/79	E	16	6	46	13	5.4	< 0.01	2.1	31.6	2.3	1.3
	H	11	6	44	52	5.2	0.03	2.1	31.6	2.2	1.2
27/XII/79	E	10	15	10	10	3.3	0.02	2.0	31.3	2.1	1.3
	H	3	71	12	14	3.0	0.02	2.0	31.5	2.0	1.2
17/I/80	E	9	2	27	10	3.2	0.01	1.6	29.6	2.2	1.3
	H	15	2	102	75	5.2	0.05	1.6	31.8	2.2	1.3
7/II/80	E	8	6	114	4	5.1	0.03	1.7	29.8	2.0	1.2
	H	14	13	122	14	4.8	0.03	1.8	30.1	2.1	1.3
21/II/80	E	0	3	0	0	4.8	0.01	1.7	31.3	2.2	1.5
	H	4	5	47	0	5.2	0.02	1.7	37.2	2.2	1.6
20/III/80	E	6	8	72	2	5.2	0.01	1.7	29.6	2.0	1.3
	H	12	7	130	6	5.6	0.02	1.7	30.1	2.0	1.3
10/IV/80	E	8	4	7	6	6.0	0.01	1.7	30.1	2.0	1.2
	H	10	6	10	14	6.2	0.01	1.7	30.0	2.0	1.2
1/V/80	E	12	5	21	22	14.2	0.02	1.6	27.0	2.0	1.2
	H	10	4	19	8	5.4	0.20	1.6	26.0	2.0	1.2
22/V/80	E	8	2	18	2	5.5	0.01	1.7	22.3	2.2	1.2
	H	32	18	27	52	5.8	0.25	1.7	22.6	2.2	1.2
12/VI/80	E	16	8	8	6	5.7	0.02	1.8	38.4	2.2	1.4
	H	104	82	10	14	5.8	0.03	1.7	33.2	2.1	1.3
3/VII/80	E	6	0	29	2	4.0	0.02	1.7	28.9	2.1	1.4
	H	8	1	26	4	3.3	0.01	1.7	28.6	2.1	1.4
24/VII/80	E	6	2	21	0	5.0	0.01	1.6	25.9	2.0	1.3
	H	6	1	22	0	5.7	0.01	1.6	24.2	2.0	1.3
14/VIII/80	E	1	3	12	0	3.9	< 0.01	1.6	27.5	2.0	1.2
	H	6	3	14	0	4.2	< 0.01	1.5	27.3	2.0	1.2
4/IX/80	E	3	0	87	2	5.6	0.03	-	-	-	-
	H	22	9	107	92	6.2	0.14	-	-	-	-
25/IX/80	E	4	5	-	10	4.4	0.01	1.5	26.2	2.0	1.3
	H	17	9	-	146	2.9	0.05	1.6	33.9	2.0	1.4
29/X/80	E	6	2	64	2	6.0	0.02	1.6	33.4	2.1	1.1
	H	7	3	128	2	6.2	0.03	1.6	33.1	2.1	1.2
12/XI/80	E	4	2	86	4	5.7	0.03	1.6	33.7	2.1	1.1
	H	4	3	115	3	5.8	0.03	1.6	33.4	2.0	1.1
27/XI/80	E	5	0	72	12	5.5	0.02	1.6	29.0	2.2	1.2
	H	4	0	94	14	5.7	0.02	1.6	31.8	2.0	1.2
18/XII/80	E	10	2	28	27	4.2	0.05	1.3	26.2	1.9	1.1
	H	23	1	26	20	4.1	0.05	1.5	29.4	2.0	1.3

Table 8.3 (cont.)

Date	Depth (m)	Total-P (µg/l)	PO_4-P (µg/l)	NO_3-N (µg/l)	NH_4-N (µg/l)	SiO_2 (mg/l)	Fe (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)
9/I/81	E	10	2	17	17	4.0	0.05	1.6	29.5	2.0	1.2
	H	14	14	14	22	4.3	0.05	1.6	28.4	2.0	1.2
29/I/81	E	8	4	10	28	4.0	0.05	1.5	25.5	2.0	1.0
	H	8	4	46	27	3.9	0.04	1.6	31.8	2.0	1.1
26/II/81	E	1	1	8	20	3.8	0.02	1.7	30.0	2.2	1.4
	H	0	0	18	32	3.8	0.03	1.8	31.6	2.3	1.4
26/III/81	E	5	2	8	18	4.6	0.02	-	-	-	-
	H	10	2	25	20	4.7	0.03	-	-	-	-
23/IV/81	E	24	0	8	24	4.6	0.05	1.8	31.8	2.3	1.4
	H	10	1	12	20	5.0	0.22	1.8	32.6	2.4	1.4
29/V/81	E	18	4	6	14	2.0	0.00	-	-	-	-
	H	24	2	5	23	2.8	0.15	-	-	-	-
1/VII/81	E	17	2	14	20	4.6	0.03	-	-	-	-
	H	14	1	9	18	4.8	0.03	-	-	-	-
3/VIII/81	E	20	5	12	-	4.2	0.01	-	-	-	-
	H	26	4	22	-	4.5	0.02	-	-	-	-
26/VIII/81	E	16	1	10	-	4.2	0.03	-	-	-	-
	H	16	1	20	-	4.5	0.09	-	-	-	-
2/X/81	E	12	1	12	14	2.0	0.04	-	-	-	-
	H	11	2	9	262	2.9	0.16	-	-	-	-
13/XI/81	E	23	4	14	148	2.2	0.02	-	-	-	-
	H	16	5	14	170	2.4	0.03	-	-	-	-
14/XII/81	E	4	2	91	12	3.0	0.00	-	-	-	-
	H	6	1	111	22	3.5	0.01	-	-	-	-
19/I/82	E	7	6	35	21	1.5	0.01	-	-	-	-
	H	15	6	48	92	1.6	0.01	-	-	-	-
24/II/82	E	10	1	24	48	5.2	0.02	-	-	-	-
	H	17	4	87	132	5.0	0.07	-	-	-	-
23/III/82	E	-	-	-	-	-	-	-	-	-	-
	H	-	-	-	-	-	-	-	-	-	-
27/IV/82	E	20	3	18	60	6.2	0.02	-	-	-	-
	H	52	19	22	384	6.2	0.04	-	-	-	-
20/V/82	E	13	4	42	43	6.4	0.04	-	-	-	-
	H	58	40	44	578	6.4	0.08	-	-	-	-
28/VI/82	E	132	2	16	26	6.0	0.03	-	-	-	-
	H	10	2	43	104	5.4	0.02	-	-	-	-
19/VII/82	E	10	4	12	56	5.7	0.02	-	-	-	-
	H	22	22	15	471	6.0	0.30	-	-	-	-
24/VIII/82	E	5	2	16	8	6.1	0.03	-	-	-	-
	H	5	2	14	81	6.1	0.04	-	-	-	-
5/X/82	E	6	3	48	32	5.7	0.01	-	-	-	-
	H	20	13	23	54	5.8	0.14	-	-	-	-
8/XI/82	E	6	4	86	39	5.7	0.05	-	-	-	-
	H	7	3	90	26	5.8	0.02	-	-	-	-

from <1 to 125 µg/l. Values tended to be higher during the early part of the wet season; at other times, epilimnetic and hypolimnetic concentrations were similar.

8.3.4 Nitrogen

NO_3-N concentrations averaged 31 µg/l and 45 µg/l in the epilimnion and hypolimnion respectively (Table 8.3 and 9.1). Concentrations in the upper part of the water column tended to be higher during the periods of complete mixing (Fig. 8.3), but seasonal variation was not always very clearly defined. The influence of the mixing regime on inorganic nitrogen concentrations is further discussed below. An example of the relationship between NO_3-N levels and primary production is discussed in Section 8.4.

During periods of stratification and hypolimnetic oxygen depletion, NO_3-N concentrations just above the sediments decreased, presumably as a result of denitrification activity (for example, the period between 20/V/82 and 24/VIII/82, Table 8.3).

NH_4-N concentrations were often low throughout the water column, but at times increased near the sediments when the lake was stratified. This was especially evident in 1982, further indicating that stratification was more prolonged in that year than in previous years.

Data from 2/X/81 and 13/XI/81 provide a good example of the influence of lake turnover on water quality (Table 8.3, Fig. 8.5). On 2/X/81, the lake was stratified, with anoxic water below 15 m. The hypolimnetic NH_4-N concentration on this date was 262 µg/l. By 13/XI/81 or shortly before that time overturn had occurred, as indicated by the uniform but low oxygen and temperature profiles (Fig. 8.2). Mixing distributed the NH_4^+ accumulated in the hypolimnion into the overlying water, and for a short time increased NH_4-N concentrations throughout the water column to about 150 µg/l. By 14/XII/81, however, most of the NH_4^+ had been oxidized (e.g. by microbial nitrification), lost to the atmosphere, or taken up by phytoplankton. The net result was low NH_4-N, but high NO_3-N concentrations one month after overturn. Two months later stratification had again set in, NO_3-N was being depleted in the surface water (presumably by phytoplankton uptake), and NH_4-N was accumulating in the hypolimnion.

The ratio of inorganic nitrogen to total phosphorus (N:P) in the epilimnetic water of L. de Yojoa ranged from 0.3 to 25.8, with a mean value ($\pm$ 1 standard deviation) of 8.4 ($\pm$ 8.1) (Table 9.1). Ratios were higher between November and March than during the rest of the year.

8.3.5 Iron

Iron was always present at low concentrations in L. de Yojoa except in the hypolimnion at the beginning and end of the wet season. Even then, concentrations were never high (Fig. 8.5, Table 8.3). For example, on the series of sampling dates discussed above in the context of inorganic nitrogen (2/X/81, 14/XII/81), hypolimnetic iron concentrations increased to 0.16 mg/l while the lake was still stratified and then fell to 0.03 mg/l after turnover had occurred.

8.3.6 Silica

The average concentration of (total) SiO_2 was 4.8 mg/l in both epilimnetic and hypolimnetic water. There were no clear or consistent seasonal trends, although some periods were characterized by unusually low SiO_2 levels, e.g. October 1981 - January 1982. The reason for these low levels is not known. As previously noted in Section 7.4.5, the SiO_2 data do not allow for any detailed interpretation because total, and not dissolved, concentrations were measured.

8.4 PRIMARY PRODUCTION

Primary production (PPR) was measured in Lago de Yojoa every 3 to 4 weeks, from June 1980 to November 1982. Results are presented here in three forms: Table 8.4 lists the complete data set. Fig. 8.7 is a graph summarizing seasonal variation in total (areal) and maximum (at any one depth) PPR. Fig. 8.6 presents a series of profiles showing the variation of PPR with depth in the water column.

There was usually measurable PPR occurring down to depths of 13-15 m. The typical PPR profile in this lake was characterized by a subsurface peak, often at 3 - 6 m. This pattern presumably resulted from the combination of high levels of solar radiation and relatively clear water, leading to inhibition of photosynthesis in the surface layers. Absence of a strong sub-surface productivity peak usually coincided with low light levels. Two exceptions, however, were 24/VII/80 and 14/VIII/80, when high levels of solar radiation were not associated with sub-surface productivity maxima. Total PPR and production efficiency were correspondingly low on both dates (Table 8.4). The reason(s) for these "anomalies" is (are) not known; unfortunately no phytoplankton counts are available from that time to assist in further interpretation.

The rate of PPR at the surface on 1/VII/81 was apparently very high, over 7X the next highest depth-specific rate observed in L. de Yojoa. This high value almost certainly resulted from the inclusion in the PPR incubation bottles of high concentrations of the colonial blue-green alga, *Microcystis*. On very calm days, this species rises to the surface and forms a dense layer. The 0 m water sample was presumably taken from this layer since large colonies were observed on the PPR filters. While the measured rate of 149 mg C/m^3/hour was probably representative of the production occurring at the surface itself, it is unlikely that it provided a realistic estimate of the production within the upper 2 m of the water column. The total PPR and production efficiency were therefore probably overestimated on this date.

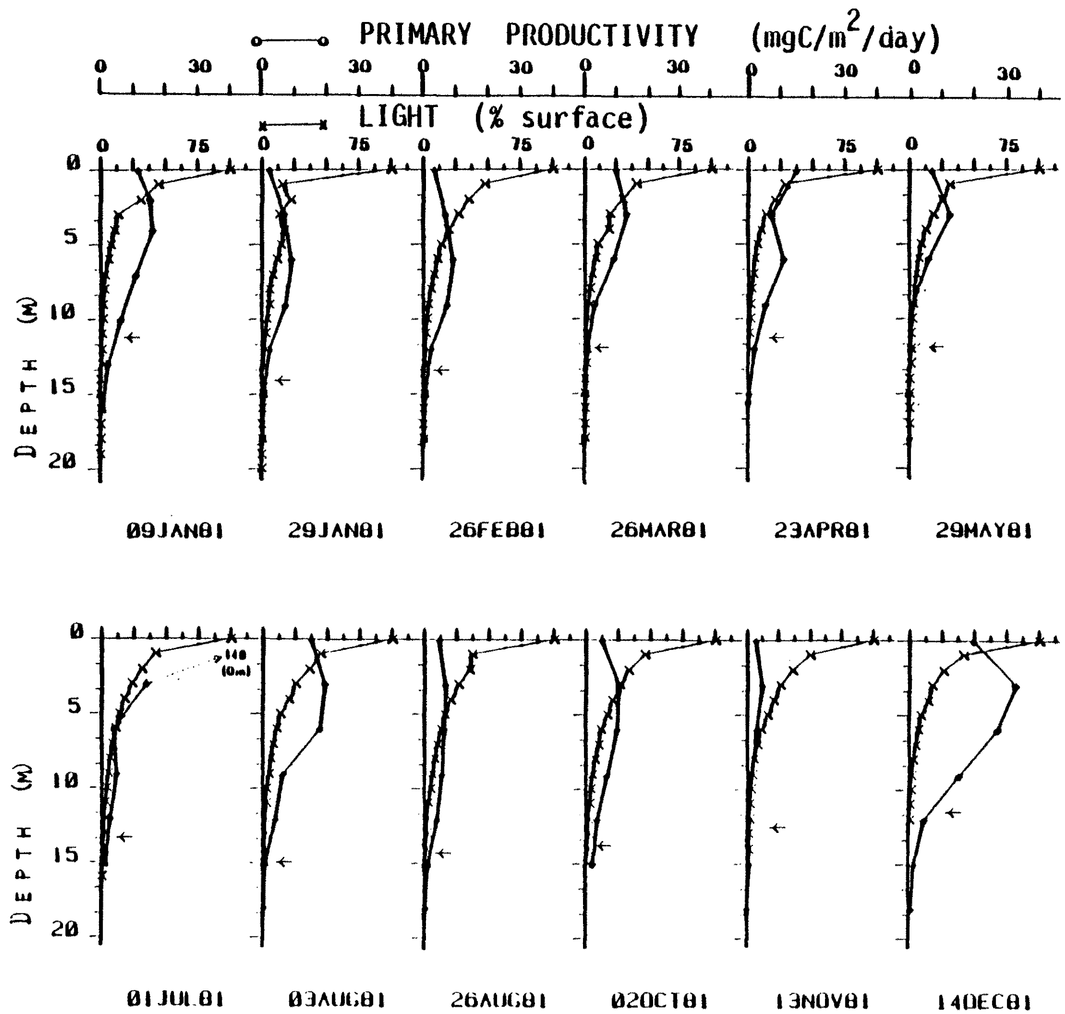


Figure 8.6: Depth profiles of light and primary productivity, L.de Yojoa. (The arrows refer to the depth of 1% surface light).

Figura 8.6: Perfiles de profundidad de luz y productividad primaria en el L. de Yojoa. (Las flechas indican la profundidad donde hay 1% de la superficial) .

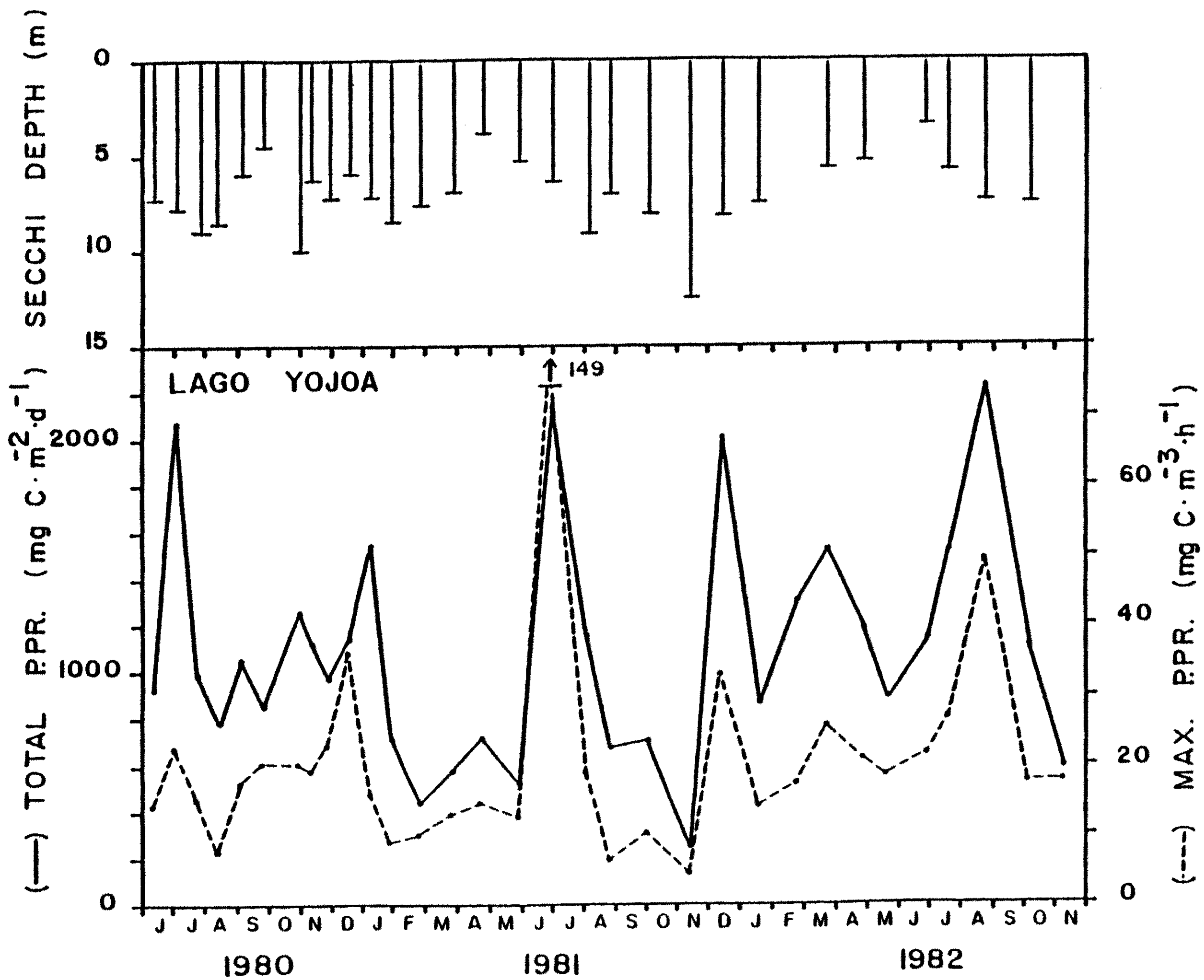


Figure 8.7: Total and maximum primary production, L. de Yojoa.

Figura 8.7: Productividad primaria, total y máxima, en el L. de Yojoa.

Table 8.4: Primary production, L. de Yojoa.

Tabla 8.4: Productividad primaria en el L. de Yojoa.

1980

	12/VI	3/VII	24/VII	14/VIII	4/IX	25/IX	29/X	12/XI	27/XI	18/XII
0 m (mg C·m^{-3}·h^{-1})	14.4	16.3	15.2	4.6	12.5	20.3	10.3	19.3	22.9	20.3
2 m " " "	7.4	19.0	9.3	7.2	9.0	20.4	19.2	19.3	20.8	36.3
4 m " " "	10.4	22.7	9.6	7.7	12.4	13.0	20.3	16.6	17.5	20.0
7 m " " "	5.9	20.0	9.4	7.7	17.6	6.0	15.0	6.6	7.9	5.6
10m " " "	3.8	9.3	6.2	7.1	3.6	2.0	8.2	3.2	3.8	1.0
13m " " "	1.9	4.9	3.7	6.8	1.3	0.6	2.7	0.8	0.9	0.3
16m " " "	3.5	1.2	1.8	4.8	13.7	0.1	1.3	0.3	0.1	0.2
Average (mg C·m^{-3}·day^{-1})	58.3	129.5	61.9	49.1	65.9	53.6	78.4	70.2	60.9	71.6
Total (mg C·m^{-2}·day^{-1})	933.3	2072.6	990.8	785.0	1054.0	857.7	1254.1	1123.3	974.4	1146.0
Efficiency (x10^{-4} per (calorie of light)	2.38	3.71	1.93	1.44	2.25	2.01	3.01	3.87	3.44	4.82
Secchi Depth (m)	7.25	7.8	9.0	8.6	5.9	4.5	10.05	6.3	7.3	5.9
Total light for day (Langleys)	392	558	514	545	468	426	417	290	283	238

1981

	9/I	29/I	26/II	26/III	23/IV	29/V	1/VII	3/VIII	26/VIII	2/X
0 m (mg C·m^{-3}·h^{-1})	11.6	0 m 2.2	3.4	9.7	14.8	6.9	149.0	14.8	4.5	5.0
2 m " " "	15.5	3 m 6.7	7.4	13.2	7.2	12.8	13.9	19.1	6.6	10.5
4 m " " "	16.1	6 m 9.2	10.3	9.0	11.1	5.9	4.0	17.9	6.2	9.7
7 m " " "	10.6	9 m 7.3	6.1	3.3	5.4	1.3	4.8	6.2	5.5	6.3
10m " " "	6.0	12 m 2.5	1.9	0.9	1.8	0.3	2.7	3.7	3.9	3.4
13m " " "	2.3	15 m 0.7	0.6	0.2	0.3	0.2	1.3	0.7	1.0	2.3
16m " " "	0.8	18 m 0.2	0.2	0.1	0.0	0.1	-	0.3	0.2	-
Average (mg C·m^{-3}·day^{-1})	96.6	39.9	24.6	32.1	39.9	29.0	142.8	64.3	37.7	47.3
Total (mg C·m^{-2}·day^{-1})	1544.9	718.1	442.4	577.2	718.8	521.4	2141.4	1158.0	678.4	709.4
Efficiency (x10^{-4} per (calorie of light)	5.03	1.91	1.32	1.24	1.43	-	4.29	2.47	2.34	2.16
Secchi Depth (m)	7.2	8.5	7.6	6.9	3.9	5.3	6.4	9.2	7.0	8.1
Total light for day (Langleys)	307	375	335	465	502	-	499	468	290	329

Table 8.4 (cont.)

	1981		1982				
	13/XI	14/XII	19/I	24/II	23/III	27/IV	20/V
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	2.8	19.5	9.1	6.4	12.6	12.6	7.8
3 m " " "	4.8	33.2	14.4	17.6	25.8	21.2	18.8
6 m " " "	2.6	27.1	12.0	16.6	17.1	16.9	16.1
9 m " " "	1.3	15.3	3.1	12.1	12.8	7.9	4.9
12m " " "	0.8	4.6	2.1	5.7	7.9	2.2	1.8
15m " " "	0.6	1.7	0.6	2.0	2.1	0.1	0.0
18m " " "	0.0	0.7	0.1	0.2	0.5	0.1	0.6
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	14.0	111.5	48.3	72.4	84.9	65.9	49.6
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	251.6	2007.2	868.3	1303.3	1528.6	1185.8	893.7
Efficiency ($x10^{-4}$ per (calorie of light)	0.97	5.61	4.28	4.16	3.24	2.73	2.97
Secchi Depth (m)	12.6	8.2	7.5	-	5.7	5.3	-
Total light for day (Langleys)	260	358	203	313	471	434	301

	1982				
	28/VI	19/VII	24/VIII	5/X	9/XI
0 m (mg $C \cdot m^{-3} \cdot h^{-1}$)	12.0	14.8	15.2	14.1	17.9
3 m " " "	21.8	26.9	49.4	17.7	12.3
6 m " " "	19.5	21.6	30.1	11.2	4.9
9 m " " "	7.3	9.6	15.4	4.6	1.1
12 m " " "	2.2	3.7	4.2	1.7	0.2
15 m " " "	0.4	1.3	0.6	1.3	0.1
18 m " " "	-	0.0	0.0	0.0	0.0
Average (mg $C \cdot m^{-3} \cdot day^{-1}$)	76.2	84.4	123.4	61.7	32.7
Total (mg $C \cdot m^{-2} \cdot day^{-1}$)	1143.4	1519.0	2321.2	1110.4	589.3
Efficiency ($x10^{-4}$ per (calorie of light)	2.68	2.99	4.86	4.35	4.99
Secchi Depth (m)	3.4	5.8	7.4	7.5	-
Total light for day (Langleys)	426	506	467	255	118

Total PPR (i.e. below 1 m^2 of lake surface) ranged from a low 252 mg C/m^2/day to a high 2141 mg C/m^2/day (2073 mg C/m^2/day if 1/VII/81 is excluded from consideration). Production efficiency varied between 0.97 X 10^{-4} and 5.61 X 10^{-4} per calorie of light (note that these extreme values occurred on consecutive sampling dates in 1981; see below). Higher values were more characteristic of the dry season.

Seasonal variation in total PPR and, especially, maximum PPR at any depth (P_{max}), were characterized by both wet season and dry season peaks which corresponded to periods of deep mixing. Note, for example, the increase in PPR and production efficiency between 13/XI/81 and 14/XII/81 (Fig. 8.7). Just before 13/XI/81, the lake had mixed completely, introducing large quantities of NH_4-N to the surface waters (Figs. 8.5). By December this NH_4^+ had been oxidized to NO_3^- and the increased nutrient levels presumably stimulated phytoplankton growth and leading to an increase in PPR. Production efficiency increased by over 400% at this time. By January, NO_3-N levels were lower, presumably because this nutrient had been partially re-incorporated into the phytoplankton (see section 8.3).

Similarly, in August 1982, PPR increased sharply following deep mixing which occurred at some time between 19/VII/82 and 24/VIII/82 (evidence that mixing had occurred is indicated by the reduction in hypolimnetic NH_4-N concentrations between these two dates).

PPR levels were, for some unknown reason, lower in 1981 than in 1980 and 1982. Average levels of solar radiation were not significantly lower on the sampling dates in 1981. Table 8.5 summarizes the seasonal distribution of total PPR through the three year period of the study. It will be further discussed in Section 9.

Table 8.5: Primary production in L. de Yojoa, 1980 - 1982.

Tabla 8.5: Productividad primaria en L. de Yojoa, 1980 - 1982.

Period	Primary Production ($gC/m^2/2$ months)		
	1980	1981	1982
Jan - Feb	--	51.17	72.05
Mar - Apr	--	35.86	83.13
May - Jun	91.68	61.30*	63.48
Jul - Aug	70.37	79.72*	104.61
Sept - Oct	62.30	35.96	60.89
Nov - Dec	69.91	66.67	51.85
Annual Total ($gC/m^2/yr$)	--	330.65	436.01

*These values are probably slightly overestimated because of the inclusion of the data point for 1/VII/81 (-- see text).

8.5 PHYTOPLANKTON

Phytoplankton counts from 1980 and 1981 are presented in Appendix 4. A similar caution with respect to species identifications as the one expressed in section 7.7 should be applied to the data contained in these tables. Phytoplankton densities are summarized by genus in Table 8.6. On those dates when depth-specific samples were taken, average water column densities were calculated for inclusion in this table.

The phytoplankton community of L. de Yojoa is dominated by diatoms (Bacillariophyceae), blue-greens (Cyanophyta) and a few species of green algae (Chlorophyta). The most abundant diatom genera were _Melosira_, _Synedra_ and _Navicula_. The first two of these were present mainly during the dry season (January - April), whereas the latter was present at moderate densities

Table 8.6: Phytoplankton densities (cells/ml), L.de Yojoa, 1981

Tabla 8.6: Densidades de fitoplancton (células/ml) en el L. de Yojoa, 1981.

Date	29/I/81	26/III/81	23/IV/81	1/VII/81	3/VIII/81	2/X/81	13/XI/81
Depth (m)	0-13	0-12	0-13	0-12	0-12	0-15	0-15
Genus							
Chlorophyta							
Carteria	-	7	-	174	4	11	3
Chlamydomonas	-	-	-	224	24	36	25
Polytoma	-	-	-	-	-	-	1
Eudorina	-	-	-	-	-	-	1
Gonium	53	-	-	13	53	--	6
Pleodorina	-	-	-	-	-	-	10
Asterococcus	182	77	171	154	174	2	179
Gloeocystis	-	-	69	-	-	-	-
Mesostigma	-	-	-	-	4	26	2
Tetraedron	-	7	-	-	-	1	-
Ankistrodesmus	-	-	-	21	3	21	4
Cerasterias	-	-	-	-	-	2	-
Eremosphaera	-	-	-	13	1	-	21
Kirchneriella	-	-	-	30	-	-	-
Oocystis	38	7	45	52	40	11	79
Scenedesmus	-	28	38	-	-	-	-
Pediastrum	-	7	2	-	-	-	-
Elakatothrix	-	-	-	34	-	-	-
Cosmarium	13	21	-	-	-	-	-
Gonatozigon	-	-	-	-	3	-	2
Staurastrum	-	-	-	21	1		21
Euglenophyta							
Trachelomonas	-	-	-	-	-	28	-
Pyrrhophyta							
Gymnodinium	-	-	24	-	5	5	4
Peridinium	21	-	-	-	4	-	2
Cryptophyta							
Chroomonas	-	14	-	427	21	28	46
Cryptomonas	-	364	-	-	20	3	19
Chrysophyta							
Xanthophyceae							
Centritractus	4	-	15	34	3	-	2
Chrysophyceae							
Rhizochrysis	-	-	-	-	-	21	-
Ochromonas	-	-	-	97	-	-	-
Dinobryon	-	-	-	-	1	-	21
Mallomonas	-	84	-	258	14	29	16
Bacillariophyceae							
Melosira	227	56	69	-	1	-	21
Synedra	8	126	13	21	-	-	3
Achnathes	-	34	3	-	-	-	-
Cocconeis	6	-	17	-	1	21	21
Navicula	14	14	28	18	21	24	29
Cymbella	8	21	4	-	-	-	-
Surirella	4	28	-	-	-	-	21
Cyanophyta							
Aphanocapsa	244	63	132	834	56	37	91
Aphanothece	208	384	120	111	22	151	15
Chroococcus	296	-	-	240	--	35	-
Gloeocapsa	41	369	-	112	32	4	19
Gloeothece	-	-	-	-	-	4	-
Merismopedia	-	-	-	-	1	-	21
Microcystis	49	55	-	-	-	1	-
Synechococcus	-	-	-	41	-	-	-
Oscillatoria	-	711	71	-	7	-	3
Nodularia	-	-	120	-	-	1	-

throughout the year. As a group, the diatoms were most important during the first part of the year (in 1981, at least). Of the Chlorophyta, the colonial genus Asterococcus (Order: Tetrasporales) was usually dominant, both in terms of numbers and, probably, biomass. It showed little evidence of seasonal variation, except for low densities on 2/X/81. Small flagellate species (Carteria, Chlamydomonas) were only common on one sampling date, 1/VII/8, a situation very different from that in L. Yure where this group is abundant during most of the year.

In addition to the higher flagellate densities observed on 1/VII/81, two other genera were also abundant at that time, Chroomonas and Mallomonas. Both are relatively small forms, and Mallomonas tends to be characteristic of hard-water lakes (Prescott 1979).

In terms of biomass, blue-green algae were clearly the most important group in L. de Yojoa. Adequate biomass data are not available for all the sampling dates, and the large colonial forms of some of the blue-greens made it very difficult to obtain a truly representative estimate of cell densities. However, visual inspection of the samples made it obvious that the blue-green species were dominant. Although many blue-greens fix nitrogen, the species in L. de Yojoa are not nitrogen fixers.

Table 8.6 shows the major blue-green genera in 1981 as being Aphanocapsa and Aphanothece. The first of these forms was identified on the basis of identifications previously made in Davis in 1980. However, inspection of the large-scale structure of the colonies strongly suggested that they were in fact Microcystis aeruginosa and not Aphanocapsa.

In 1981, blue-green densities (and biomass) were highest between January and July. There was an apparent bloom of Aphanocapsa/Micocystis on 1/VII/81. This was the date when unusually high primary productivity was measured at the surface. It has previously been suggested (section 8.4) that this high productivity value was the result of an accumulation of phytoplankton biomass at the surface, probably because of unusually calm conditions. Unfortunately, depth specific phytoplankton counts are not available from that date, so it is not possible to adequately correlate primary production and cell densities. However, since integrated phytoplankton samples were collected by pooling depth-specific samples (0,3,6 m ...), it is quite possible that a surface accumulation of *Aphanocapsa/Microcystis* would have resulted in the high integrated sample cell densities observed on this date.

Although the densities and biomass of blue-green algae were apparently lower after July than before (during 1981), rates of primary production remained about the same (Fig. 8.7), and production efficiency actually increased slightly (Fig. 9.2). Although no counts are available from 1982, a significant change in phytoplankton community structure was noted during that year. *Aphanocapsa/Microcystis* became much less abundant, and the dominant genus during much of the year was *Oscillatoria*. It is not known if this change in phytoplankton species composition was responsible for the higher primary productivity and production efficiencies measured in 1982.

The depth-specific cell counts (Appendix 4) illustrate the effect of a well-mixed eplimnion on the phytoplankton community. Cell densities were generally uniform over the 0-15 m depth range. In November 1981, the mixed zone was deeper than the euphotic zone, and so a proportion of the cells were experiencing almost aphotic conditions (Fig. 9.1). Further discussion of the Yojoa phytoplankton community is deferred to section 9.

8.6 ZOOPLANKTON

A total of 20 taxa were recorded from the zooplankton community of L. de Yojoa, but only abut 50% of these were ever numerically abundant. Results are presented in Appendix 3 and represent the means of two replicate samples, together with their coefficients of variation. The data are summarized in Fig. 8.8 which shows seasonal variation in the density of the most common species. Unfortunately, biomass values could not be calculated since all the samples were processed in Honduras, where a microbalance was not available. During the second half of 1980 and the beginning of 1981 two species of large cladocera were almost equally abundant, Daphnia pulex and Diaphanosoma leuchtenbergianum. The latter species reached its peak abundance at the end of October. By June 1981 it was very rare, but did re-appear in low numbers the following October. Daphnia densities also decreased through May 1981 but then, in contrast to Diaphanosoma, increased to reach a peak of over 200,000 individuals/m^2 in October. In 1982, Daphnia densities fluctuated more irregularly, at levels similar to those observed in 1980.

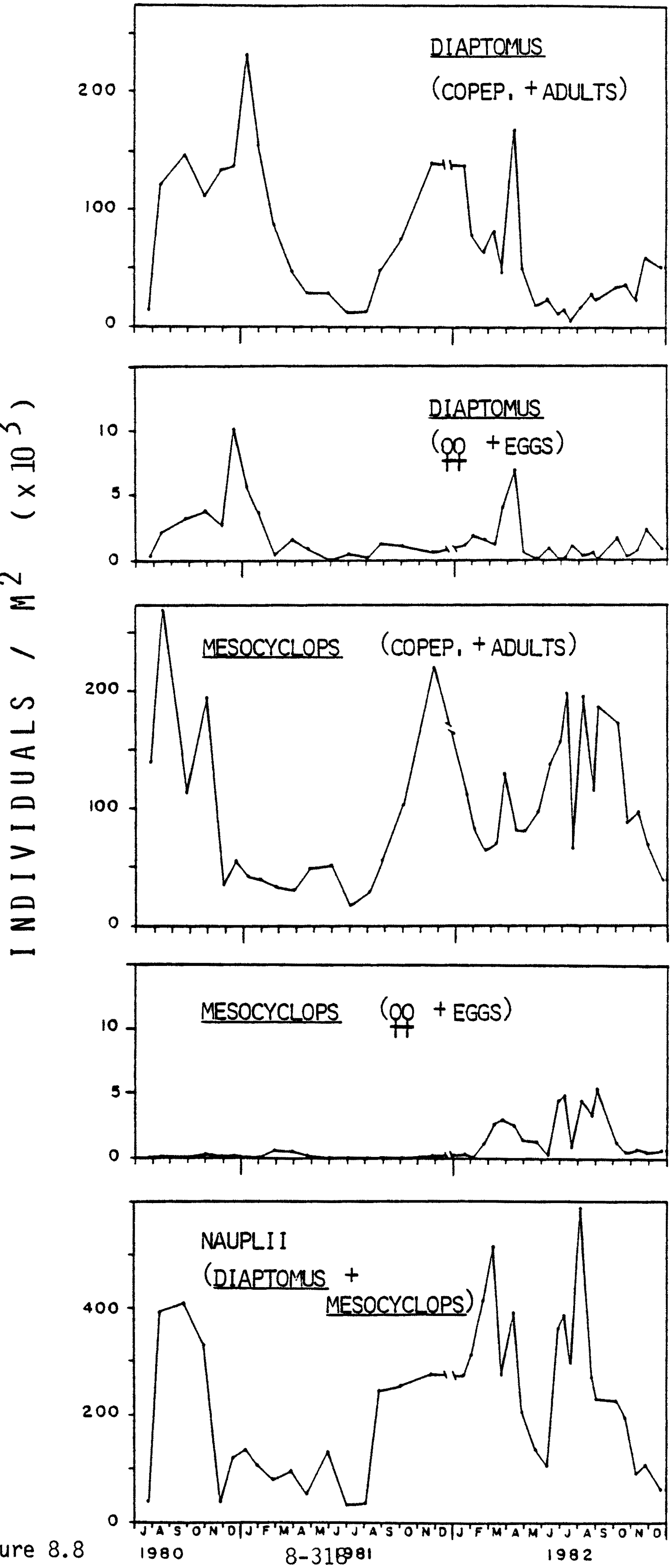
A third species, Ceriodaphnia sphaericus, was the most abundant cladoceran during 1980, but, because it is much smaller than either Daphnia or Diaphanosoma, it probably did not represent a major component of total zooplankton biomass. Ceriodaphnia densities decreased in advance of Diaphanosoma densities. After May 1981, a second species, C. rigaudi, was occasionally observed in addition to C. sphaericus. Both were very rare, however.

Three copepod species were recorded from the lake. One of these, a large cyclopoid, was rare, and its identity is uncertain. One of the other two was a calanoid (Diaptomus colombiensis) and the second was a cyclopoid (Mesocyclops inversus). The latter is a very small species and so presumably represented a smaller biomass component than Diaptomus.

Densities of both species exhibited similar but not identical seasonal trends. Diaptomus copepodites and adults (these stages were not counted

Figure 8.8: Seasonal variation in the abundance of the major zooplankton species in L. de Yojoa.

Figura 8.8: Variación estacional en la abundancia de las especiés de zooplancton de mayor importáncia en el L. de Yojoa.



INDIVIDUALS / M^2 (x 10^3)
DIAPTOMUS
(COPEP. + ADULTS)
200
100
0
DIAPTOMUS
(♀♀ + EGGS)
10
5
0
MESOCYCLOPS (COPEP. + ADULTS)
200
100
0
MESOCYCLOPS (♀♀ + EGGS)
10
5
0
NAUPLII
(DIAPTOMUS + MESOCYCLOPS)
400
200
0
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1980
1981
1982

Figure 8.8

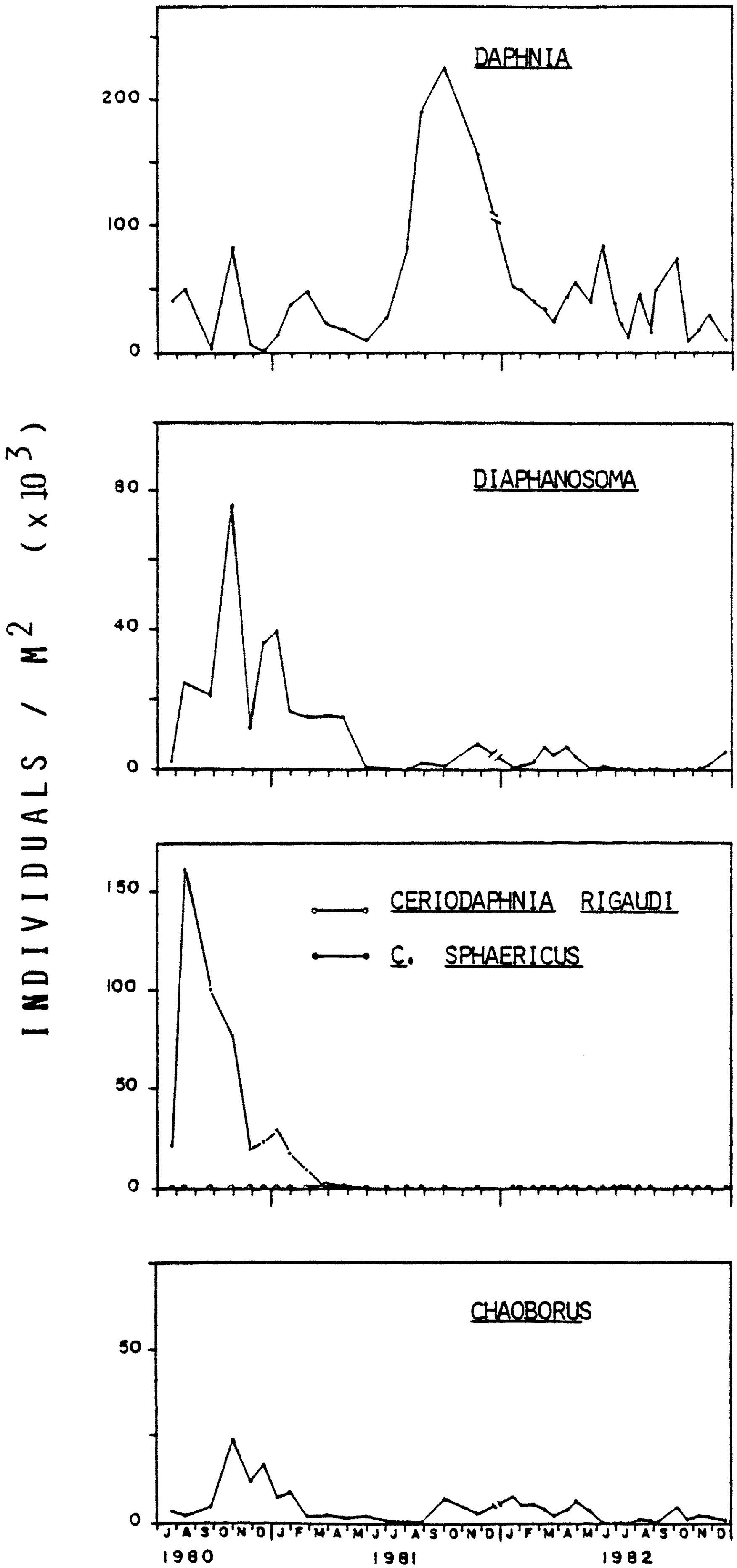


Figure 8.8 (cont.)

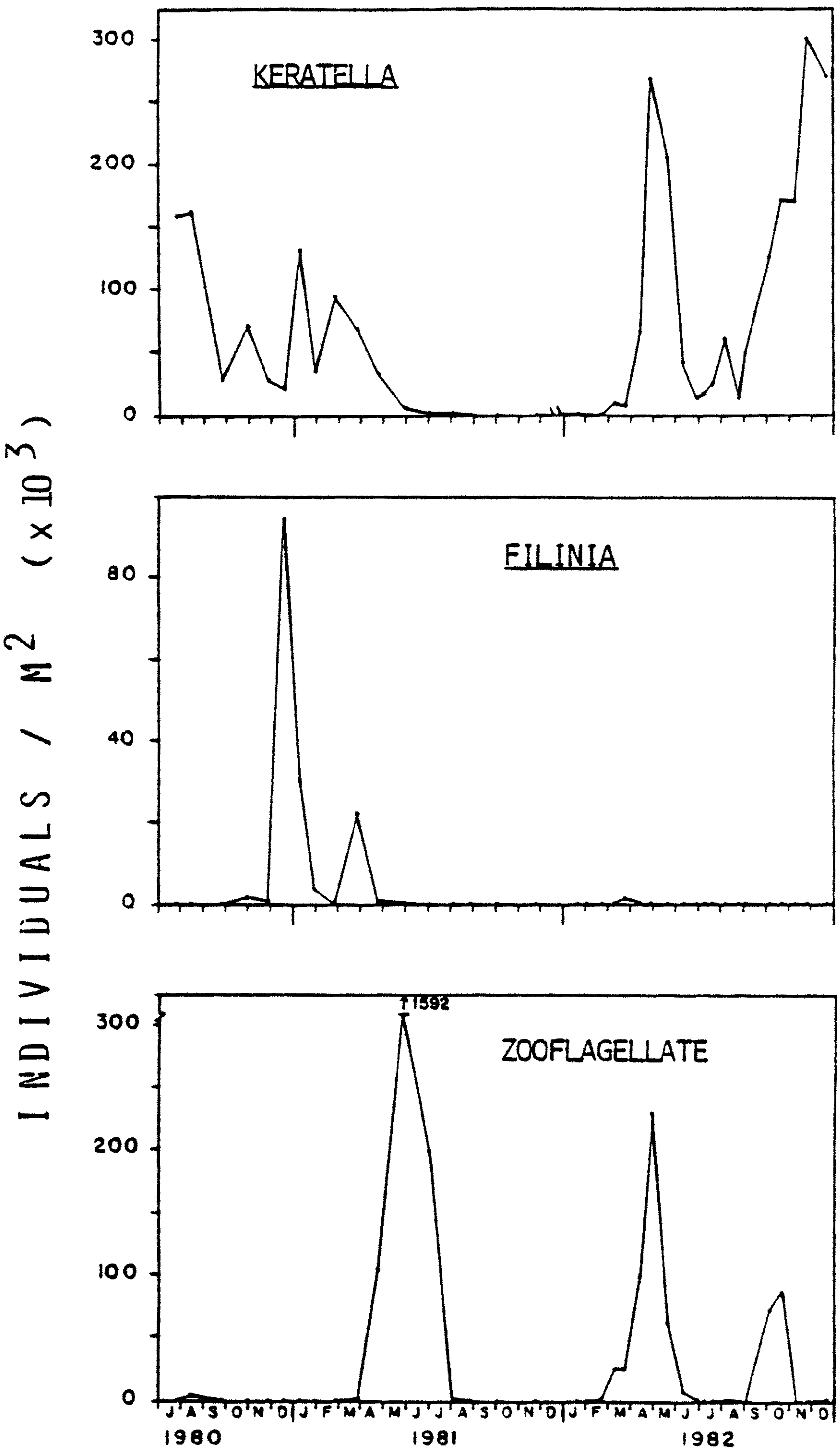


Figure 8.8 (cont.)

separately) were most abundant between August and February in 1980/81, and September and March in 1981/82. During the second half of 1982, densities increased slightly but not to the levels of the previous two years. The proportion of female *Diaptomus* which were carrying eggs tended to be higher during the latter part of the abundance peaks. However, this pattern was probably an artifact of the counting system, since mature females presumably represented a larger proportion of the copepodite + adult total at that time, i.e. more copepodites had reached the adult stage.

Mesocyclops densities were lowest during the first part of the year, both in 1981 and 1982. In 1980, densities declined from August through December, whereas in 1981 they were increasing at that time. *Mesocyclops* maintained high densities through much of 1981, the period when *Diaptomus* numbers were low. The number of *Mesocyclops* females with eggs presented an interesting pattern, because very few were reproducing during the period in 1980 when copepodite + adult densities were high. Ovigerous (egg-bearing) females were, however, present in significant numbers during 1982.

Nauplii of both species were pooled in the counts since small *Diaptomus* nauplii were difficult to distinguish from the larger stages of *Mesocyclops*. This, however, limits the usefulness of the nauplii data. Assuming that *Mesocyclops* females were producing very few eggs (and thus nauplii) in the second half of 1980, the peak in nauplii densities at that time probably represented mainly *Diaptomus*. The second peak of *Diaptomus* copepodites + adults, in January 1981, may well have represented the development to the copepodite stage of the cohort of nauplii observed in 1980. A more detailed study is needed to adequately document the population dynamics of the Yojoa copepod community.

Of the nine rotifer species, only two were at any time abundant, i.e. *Keratella americana* and *Filinia longiseta*. *Filinia* was common only during a very short period early in 1981. In all subsequent months, it was either very rare or absent from the samples (Fig. 8.8).

Keratella did not appear to show any consistent seasonal trend in abundance. Densities were relatively high until May 1981, but then remained low until April of the following year. There was a very definite bimodal abundance pattern in 1982, with low densities occurring between June and August.

At the beginning of the 1981 wet season, there was a dense "bloom" of an unidentified zooflagellate species. The peak density recorded was over 1 1/2 million individuals/m^2 of lake surface. Individuals of this species were apparently enclosed in a very thin, delicate case, or theca, and appeared to be primarily benthic, not pelagic. It was difficult to be certain of this, however, since thecae were not well preserved in the samples. If the organisms were primarily benthic or littoral, it is unclear how large numbers could have been so rapidly transported into the pelagic zone of the lake. It was interesting to note, however, that zooflagellate densities increased in 1982 during the same period as in the previous year. However in 1982, a second peak was observed in September and October.

Chaoborus densities were highest during the dry season and the latter part of the wet season (September/October - March/May). Densities decreased as the larvae pupated and subsequently emerged as adults.

In summary, the general pattern of seasonal variation in the L. de Yojoa zooplankton community was one of higher densities during the period from about September to March/April. However, these patterns were not very consistent, either between years or between species. With a data base spanning just 2 1/2 years, it is very difficult to draw detailed conclusions concerning medium-term trends in plankton population dynamics. This is especially so when there are broad shifts in species dominance, for example the change within the cladoceran community from one where _Diaphanosoma_, _Ceriodaphnia_ and _Daphnia_ were co-dominant (1980-81) to one where _Daphnia_ alone was the most important species (1981-82). Analogous shifts within the cladoceran community of L. Yure were also observed (Section 7.8) during the period of this study. Changes in zooplankton community structure will be further discussed in relation to trophic ecology of fish in sections 9 and 11.

There was no clear relationship between zooplankton abundance and primary production in L. de Yojoa. A longer-term data base, biomass measurements and estimation of zooplankton growth rates are needed to adequately investigate the relationship between primary and secondary pelagic production in this and other lakes. It should be noted, however, that total primary production as measured in the present study probably does not represent a reasonable estimate of the amount of synthesized organic matter available for use by zooplankton. During most of the period 1980-1982, the biomass dominants of the Yojoa phytoplankton community were clearly _Microcystis_ or _Oscillatoria_. Both are blue-green algae (Cyanophyta), a group which often (but not always) cannot be assimilated by either zooplanktonic organisms or fish. Furthermore, _Microcystis_ was usually present in large, macroscopic colonies, and _Oscillataria_ is a filamentous alga, thus making both species too large to be used by most, if not all, the members of the zooplankton community. However, _Microcystis_ and _Oscillatoria_ presumably were responsible for a significant proportion of the measured rates of primary production. Therefore it would appear that much of the pelagic primary production in L. de Yojoa is not used by the primary consumers (herbivores), but instead enters the detrital pathway. As detritus, however, it may find its way, via bacteria and colonized particles, to the zooplankton and then to the fish.

9. SYNTHESIS: EL CAJON LIMNOLOGY

9.1 INTRODUCTION

The two foregoing sections have presented a detailed description of the limnological studies carried out on L. Yure and L. de Yojoa. As has previously been mentioned, the main reason for undertaking these lake studies was to provide a framework for interpreting the river water quality data in terms of the El Cajón reservoir.

By first analyzing some of the principal ways in which L. Yure and L. de Yojoa differ limnologically, the present section attempts this integration of the river and lake data bases with a discussion of some important aspects of the future limnology of the El Cajón reservoir. Since this study was carried out at a time when most of the major planning decisions for the El Cajón dam had already been made and since initial monitoring of the new reservoir will soon begin, predicting initial reservoir limnology becomes rather less important than using the existing broad data base to identify those areas to which future research effort should be directed in order to adequately understand the functioning of the El Cajón reservoir ecosystem and provide management of the new system. Furthermore, a reservoir model based solely on the existing river water quality data-base, and without detailed meteorological information from the reservoir basin itself, will not yield sufficient precision to adequately identify the characteristics of what will be a fairly shallow epilimnion in L. El Cajón. However, a combination of the existing riverine data base with an initial series of observations on the thermal regime of the new reservoir will enable the use of models of sufficient complexity to realistically predict the impact of various reservoir management policies on the water quality both of the thin productive (euphotic) zone of the lake and of the river downstream from the dam.

Appendix 7 presents a brief description of a model which is being used to predict the impact of management regimes on water quality for a number of reservoirs in the U.S., the model HEC-5Q. The capabilities of this model and the type of initial, base-line data needed on the physical limnology of the new reservoir are discussed. If the necessary data are collected during the first year of the reservoir's operation, then they and the already existing data-base can be used for future predictive modelling if this becomes necessary (see, further, section 3).

The importance of a future integration of the pre-impoundment data-base with a limnological record of the developing reservoir cannot be overemphasized. This is so both for the objective of developing an effective medium- to long-term management policy for the reservoir and for making full use in future impoundment projects in Honduras of the knowledge and experience base developed during the present study.

A detailed series of suggested future studies on the El Cajón reservoir is included in the recommendations section and should be viewed as a further extension of the discussion presented here.

9.2 THERMAL STRUCTURE/MIXING REGIME

Differences in the morphometry of L. Yure and L. de Yojoa result in distinct thermal regimes in each lake. The shelter afforded L. Yure by the surrounding hills, combined with its dendritic shape and low surface area to mean depth ratio cause stratification to be more stable in this lake than in the more "open" L. de Yojoa. Wind-mixing usually maintains the thermocline below 15 m in L. de Yojoa, whereas it is often at 6 m or less in L. Yure (Figs. 7.7 and 8.2). Furthermore, a completely isothermal epilimnion is rare in L. Yure, (at least during the daytime). Surface heating and insufficient wind-mixing often result in a secondary thermal discontinuity (diel thermocline) extending to the surface.

Because the thermocline is usually deep in L. de Yojoa, mixing during the wet season is at times sufficiently strong to result in complete circulation to the lake bottom, which in turn influences nutrient concentrations throughout the water column (Table 8.3) and, probably, primary productivity (Table 8.4, Fig, 8.7). The continual deep mixing in L. de Yojoa serves to transfer much of the heat absorbed by the surface layers to deeper waters, thus resulting in an average bottom temperature 5°C higher than in L. Yure (Table 9.1). Heating of deeper water is further assisted by the low turbidity and thus high light penetration through the water column. Wet season turnover was never recorded in L. Yure, although storms do influence the depth of the primary and secondary thermoclines during June to September, and thus possibly also epilimnetic nutrient concentrations (see section 7.3.1). Complete circulation occurs in the deepest parts of this lake only when air temperatures are sufficiently low to result in an appreciable heat loss from the surface layers and thus a reduction in the density gradient. The influence of inflowing streams on the mixing regime of L. Yure is probably not significant, although the turbulence associated with high discharge rates causes localized mixing in the upper reaches. More significant for the overall mixing regime of the lake is the epilimnetic position of the main outflow (the canal taking water to L. de Yojoa). By removing warmer surface water from the lake, a surface outflow tends to lower epilimnetic temperatures during period of high flow-through, and thus decrease the stability of stratification. Conversely, hypolimnetic release of water tends to allow a more stable epilimnion to develop and cause a loss of nutrient-rich water from the aphotic zone. An exception to this occurs when the density (and momentum) of inflowing river water is such as to cause it to pass through the reservoir as a plug-flow at the same depth as the

Table 9.1: Comparative limnology of L. Yure and L. de Yojoa.

Tabla 9.1: Comparación entre la limnología de los lagos Yure y Yojoa.

Parameter	L. Yure				L. de Yojoa			
	Mean (1980-82)	St. Dev.	Range	N	Mean (1980-82)	St. Dev.	Range	N
Temp. @ surface (C)	23.1	2.1	19.7-28.8	56	24.9	2.1	20.2-27.5	39
Temp. @ bottom (C)	18.1	1.4	15.9-20.3	56	23.0	1.9	18.7-26.3	39
Conductivity @ surface (μmho/cm)	44	13	32-91	59	168	16	152-244	41
Secchi depth (m)	1.8	0.9	0.6-4.3	39	7.1	1.9	3.4-12.6	29
Extinction Coefficient (m^{-1})	1.05	0.47	0.44-2.33	48	0.33	0.11	0.23-0.52	35
% Water column O_2 < 0.5 mg/ℓ ☆	45	20	0-75	30	15	10	0-30	21
Total-P (μg/ℓ)	19	13	8-78	51	10	6	0-24	43
PO_4-P (μg/ℓ)	5	3	1-12	49	3	3	0-15	40
NO_3-N (μg/ℓ)	104	53	14-192	45	32	30	0-114	39
NH_4-N (μg/ℓ)	17	13	0-56	48	20	25	0-148	41
SiO_2 (mg/ℓ)	9.4	2.9	3.6-15.2	49	4.8	1.9	2.0-14.2	43
Fe (mg/ℓ)	0.14	0.14	0.04-0.51	49	0.02	0.01	0.00-0.05	43
Mg (mg/ℓ)	0.4	<0.1	0.2-0.5	28	1.7	0.2	1.3-2.1	25
Ca (mg/ℓ)	2.1	0.8	0.7-3.4	28	29.2	3.3	22.3-38.4	25
Na (mg/ℓ)	3.7	0.3	3.0-4.4	28	2.1	0.1	1.9-2.6	25
K (mg/ℓ)	2.4	0.2	2.0-2.9	27	1.2	0.1	1.0-1.4	25
Inorganic N : Total P	8.9	6.6	1.0-27.5	44	8.4	8.1	0.3-25.8	39
Total daily PPr † (mg C/m^2/day)								
-- 1981	946	---	341-1914		906	---	252-2141	
-- 1982	1213	---	188-4508		1194	---	589-2321	
P_{max} (mg C/m^3/day)	51.9	28.7	10.4-147.4	42	18.7 ‡	9.1	4.8-49.4	31
Efficiency (x10^{-4}/ cal. light)	2.43	1.89	0.34-11.30	42	3.06	1.29	0.97-5.61	31

★ Water chemistry data are from epilimnetic samples.

☆ % of water column where dissolved O_2 concentrations were < 0.5 mg/ℓ (concentrations < 0.5 mg/ℓ were probably in general about 0.0 mg/ℓ - see text).

† Mean PPr calculated by dividing estimated annual PPr by 365 days. Range is for individual observations.

‡ P_{max} for 1/VII/81 is omitted from calculated mean.

hypolimnetic outflow from the dam. In this situation, little mixing may occur between the inflowing and epilimnetic water masses. Absorbed solar energy is retained within the surface layers, thus increasing the stability of stratification. The epilimnetic outflow from L. Yure probably increases stratification stability in this lake, especially since stream temperatures indicated epilimnetic/metalimnetic interflow of water entering from the main tributaries.

Although similarities in the relative morphology of L. Yure and the El Cajón reservoir strongly suggest that the former lake is a better model for the latter than is L. de Yojoa, there are enough differences between the Yure and El Cajón system to make a precise prediction of the latter's thermal regime difficult. The following discussion briefly considers each of the principal variables which are likely to influence mixing in the El Cajón reservoir. Rather than making a detailed prediction of the future mixing regime, the objective of this discussion is to identify some of the major factors which, directly or indirectly, will influence both the chemical and biological limnology of the reservoir. A monitoring study, carefully designed to follow changes in the reservoir's mixing pattern, will be necessary to more fully elucidate the relative importance of each of the factors discussed below.

9.2.1 Wind

The Sulaco branch of the reservoir will be more sheltered from the prevailing north-easterly winds than will the Humuya branch. Wind mixing may therefore drive the thermocline somewhat deeper in the Humuya branch, but this differential effect is unlikely to be great. In all three main branches, the primary thermocline will usually be between 5 and 10 m and will be stabilized by a temperature gradient of about 4 to 7°C.

Secondary thermoclines, as seen in L. Yure, either extending to the surface or located at an intermediate depth, will probably form, especially if the turbidity of the surface layers is high (see below). However, the epilimnion of the El Cajón reservoir will be better mixed than it often is in L. Yure, because of greater wind fetch in the former lake.

Differences in wind regime between the Humuya, Sulaco and Yure branches may contribute to differences in the heat content of the surface layers (through evaporative cooling and conduction), which may in turn influence circulation patterns. The effect will probably be small, however, and a detailed study would be needed to demonstrate it.

9.2.2 River Inflow

River inflow will dominate the mixing regime of L. El Cajón during much of the year, as it does in other large tropical reservoirs, for example Kainji, Nigeria (Henderson 1973, Adeniji 1975), Kariba, Zimbabwe/Zambia (Balon and Coche 1974) and Cabora Bassa, Moçambique (Bond _et al_. 1978), as well as in many temperate impoundments (e.g. Kamloops Lake, Carmack _et al._ 1979).

Bottom temperatures in L. Yure average about 18°C (Table 9.1) and are determined by the temperature of the lake at turnover (December/January) and the minimum temperatures of the inflowing rivers. Hypolimnetic temperatures of the El Cajón reservoir will be several degrees warmer than those of L. Yure, because the temperature of the major inflowing rivers rarely is lower than 20°C. Since average epilimnetic temperatures of L. El Cajón will be similar to those of L. Yure (about 24-28°C), the difference between surface and bottom temperatures in the former lake will be less than that in the latter. Shading from the steep canyon walls of the new reservoir may reduce solar heating and thus thermal stability. The long fetch may provide enough wind to mix the lake somewhat deeper than expected.

The Humuya and Sulaco rivers will be cool enough to underflow through the

El Cajón reservoir in December and January. The total volume of water entering the reservoir at this time is small (about 6% of the lake's volume) and will not significantly influence the mixing regime. However, the cooler inflow will perhaps form a pool of denser water in the deepest part of the reservoir and should bring in some oxygen to this zone (see 9.3).

River temperatures during the wet season (Tables A2.1 - A2.8) will be such that most of the water entering the reservoir does so as an interflow, although high sediment loads will at times lead to an underflow along the upper reaches of the lake. The influence of river discharge on the reservoir's mixing regime will depend not only on depth of flow but also on reservoir morphometry and current velocity. The last two factors will determine the amount of mixing that occurs between river and lake water and thus how far into the reservoir river water will exist as a discrete flow. Since all three major branches of the reservoir are relatively narrow, lateral mixing is likely to be reduced at the plunge point (Ford and Johnson 1980) and it is possible that inflowing water will form a plug-flow which will move through the reservoir and exit through the penstocks. In this case, inflowing water will have little direct influence on the epilimnion and thus on the production processes occurring there. The influence of river discharge rates on the regime and nutrients dynamics of the El Cajón reservoir will be a particularly interesting and useful avenue of future research (see below and section 3).

9.2.3 <u>Surface Cooling</u>

In L. Yure, wet season storms are not sufficient to disrupt the density gradient and mix the lake to the bottom. This only occurs in December and/or January when surface cooling results in an appreciable reduction in the density gradient between surface and bottom waters.

Surface cooling during December and January will also probably increase the depth of the mixed zone in L. El Cajón and may result in nearly isothermal conditions. However, it is unlikely that wind stress and river inflow will provide sufficient energy to fully mix the deeper parts of the lake even at this time. L. Yure only mixes to the bottom during at most one to two weeks before stratification is once again established. The much greater depth of L. El Cajón means that a great deal more energy will be required to cause turnover in this reservoir.

9.2.4 Turbine Intake

Discharge from the reservoir will be hypolimnetic in both wet and dry seasons since it is anticipated that thermocline depth will be about 10 m. Circulation will probably be promoted in the upper 60 m of the water column, unless a hypolimnetic plug-flow occurs through the entire length of the reservoir. However, water below the turbine intake depth (dead storage), representing about 33% of the total reservoir volume (Motor Columbus 1977), will be largely unaffected by this discharge.

9.2.5 Turbidity

Since turbidity increases the amount of solar radiation absorbed per unit depth of water, high epilimnetic turbidity results in a greater percentage of the total absorbed energy being retained in the surface layers of a lake. This tends to increase stratification stability, but also means that more heat is lost by evaporative cooling and by re-radiation to the atmosphere during periods of lower air temperatures. Epilimnetic turbidity will be highest in the El Cajón reservoir during the wet season, as it is in L. Yure. By increasing the stability of stratification, it will tend to reduce the depth of the thermocline an thus reduce the volume of the epilimnion. A detailed study would be needed, however, to assess the relative importance of this factor for the mixing regime of L. El Cajón and possible management strategies to optimize productivity.

9.3 DISSOLVED OXYGEN

In both L. Yure and L. de Yojoa, hypolimnetic oxygen concentrations are reduced soon after stratification has been established (Figs. 7.7 and 8.2). Because the euphotic zone rarely extends below the primary thermocline (Fig. 9.1), the hypolimnion is usually totally anoxic in both lakes. Exceptions to this occur occasionally in L. Yure when density currents transport oxygenated water along the bottom of the lake (Fig. 7.20, Appendix 10), and in L. de Yojoa sporadic turnover during the wet season at times results in a temporarily oxic hypolimnion (i.e. just after stratification has been re-established).

When secondary thermoclines form in L. Yure, light penetration is usually sufficient to allow photosynthesis below the thermal discontinuity. This, together with nocturnal mixing, maintains the "primary" epilimnion oxygenated.

During much of the year, a large percentage of the total volume of the El Cajón reservoir will be anoxic (approximately 85% with an 10 m thermocline). This pattern is common to most large reservoirs, especially during the first few years of their existence. It has been estimated that between 8 and 15 years would be required to meet the total chemical oxygen demand (COD) of the vegetation in the El Cajón basin, if the lake were to mix completely once every year (Goldman and Knud-Hansen 1983). Removal and burning of some of the vegetation before inundation will certainly have reduced the total COD and the likelihood of problems arising from aquatic plant infestations. However, it is probable that the deepest parts of the reservoir will only mix as a consequence of very extreme storm events, and thus be semi-permanently anoxic. Water exiting from the penstocks will therefore be void of oxygen during much of the year and will almost certainly contain significant concentrations of hydrogen sulphide.

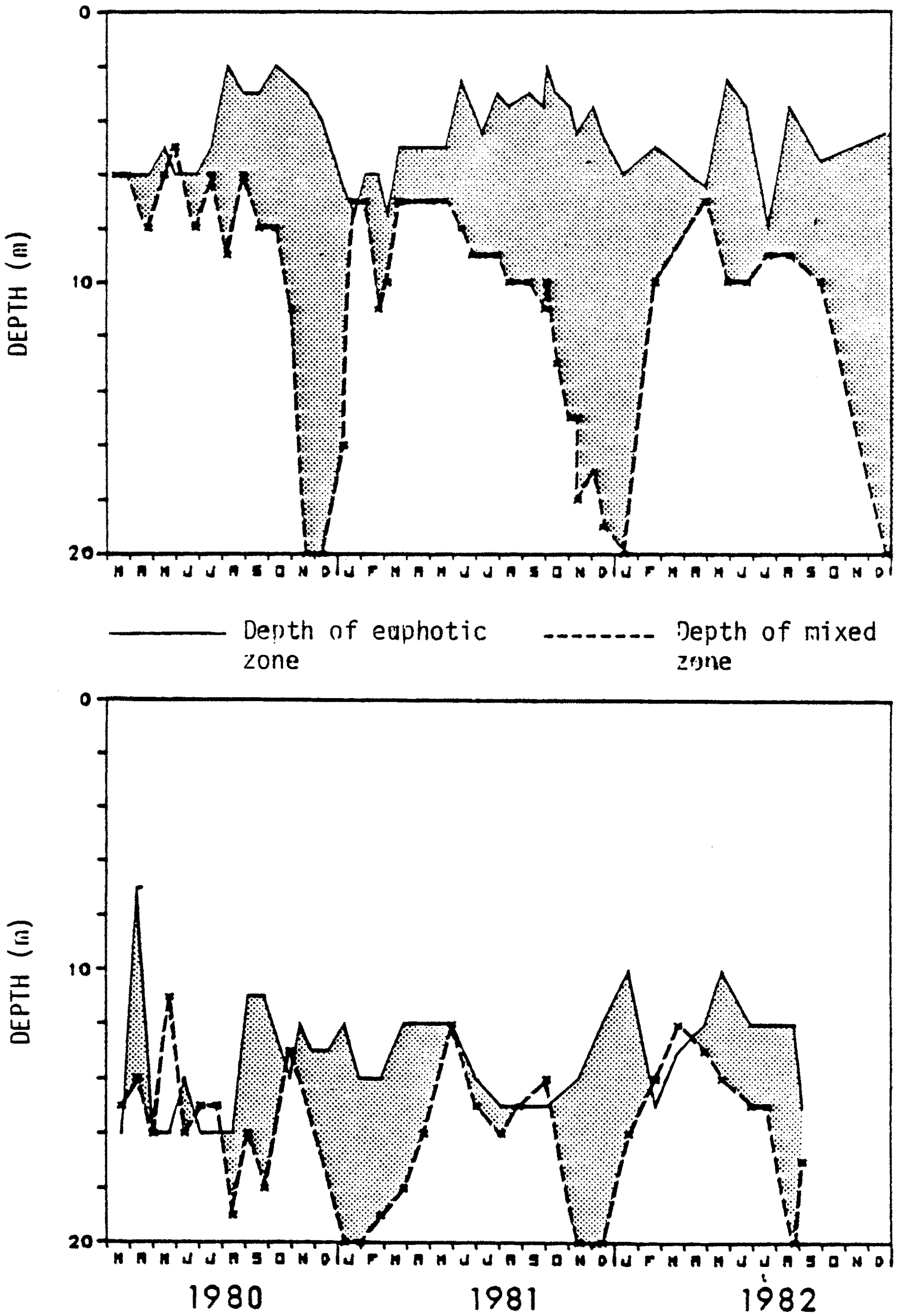


Figure 9.1: Seasonal variation in the depth of the mixed and euphotic zone in (a) L. Yure and (b) L. de Yojoa. (Shaded areas represent times presumed to be light-limited).

Figura 9.1: Variación estacional en la profundidad de la zona mezclada y la zona eufótica en (a) el L. Yure y (b) el L. de Yojoa.
(Las areas oscuras representan el tiempo cuando se supone que la fotosíntesis está limitada por la cantidad de luz.)

In addition to the terrestrial vegetation flooded by the new reservoir, organic matter produced within the lake itself (e.g. phytoplankton) will also contribute to the total oxygen demand as it sinks into the hypolimnion and is mineralized. A high biochemical oxygen demand (BOD) was never measured in the hypolimnion of L. Yure. However, hypolimnetic concentrations of hydrogen sulphide were apparently considerably higher in 1982 than in the previous year (section 7.6.7). This may have been a result of the increased levels of pelagic primary production which were observed during 1982. BOD was not measured at that time so it is not known if it increased parallel with H_2S levels, as might be expected.

Burning and removal of vegetation from the L. Yure basin before inundation presumably reduced oxygen demand in the newly formed reservoir. However, it can be noted that even with vegetation clearance, the hypolimnion rapidly became anoxic after the establishment of stratification in each of the three years of this study.

Although the hypolimnion of the El Cajón reservoir is expected to be anoxic, oxygen profiles may at times be influenced by river inflow, if the latter forms an interflow (or underflow) below the thermocline (about 10 m). In this case, a negative heterograde oxygen curve will result, especially in the upper reaches of the reservoir. That is, oxygen concentrations will decrease immediately below the thermocline, but increase again in deeper water when the latter represents the stratum occupied by the inflowing river.

9.4 NUTRIENTS

Average nutrient concentrations in L. Yure and L. de Yojoa are summarized in Table 9.1. Some of the differences between the two lakes are presumably related to the greater watershed area:lake area ratio of L. Yure and its shorter retention time, which results in a closer coupling between the watershed and lake water quality.

Total phosphorus and iron concentrations are higher in L. Yure than in L. de Yojoa during the wet season, because of increased sediment loading in the former lake. Not only is the total stream inflow:lake volume ratio lower for L. de Yojoa than for L. Yure, but also the beds of macrophytes around the shoreline of L. de Yojoa presumably serve to "filter" incoming water and modify its nutrient levels, as well as to stabilize shore-line sediments. Macrophytes can "lock up" in biomass a significant proportion of the total phosphorus in a system, especially when the phosphorus is removed entirely from the water column as it is by floating plants (Mitchell 1973).

PO_4-P is consistently low in both lakes, reflecting its rapid uptake by phytoplankton. NO_3-N concentrations are about 3x higher in L. Yure than in L. de Yojoa, reflecting the relatively high NO_3-N levels of the streams flowing into the reservoir.

The influence of mixing regime and oxygen concentrations on nitrogen and phosphorus dynamics in both lakes have been discussed in detail in sections 7 and 8. Similar patterns of seasonal and depth variation will occur in the El Cajón reservoir, but the prolonged anoxia expected to characterize the deepest parts of the lake will mean that NH_4-N and PO_4-P will reach higher concentrations than those in L. Yure.

Epilimnetic nutrient concentrations will depend to a large extent on the depth at which inflowing river water moves through the reservoir (e.g. Gloss et al. 1980), as discussed below and in section 9.2. The low NO_3-N concentrations of the Humuya, Sulaco and Yure rivers suggest that NO_3-N levels in the new reservoir will be more similar to those of L. de Yojoa than those of L. Yure, where the inflowing tributaries are relatively rich in NO_3-N (Fig. 6.4). Concentrations of total phosphorus, however, will exhibit the seasonal variation characteristic of L. Yure as wet season inflows bring large quantities of particulate and adsorbed phosphorus into the new reservoir. Further comparison between the nitrogen and phosphorus dynamics of the three lakes is deferred to section 9.5.2 where factors limiting primary production are discussed.

Concentrations of the four cations, Mg^{++}, Ca^{++}, Na^{++}, and K^{+} are quite different between L. Yure and L. de Yojoa. Monovalent ions (Na^{+} and K^{+}) are more concentrated in L. Yure, whereas divalent ions (especially Ca^{++}) are more concentrated in L. de Yojoa. These differences are presumably related to watershed geology and, especially for divalent ions, the relative importance of the groundwater component to the lake's water budgets.

The monovalent:divalent (M:D) ion ratio is 2.4 and 0.1 for L. Yure and L. de Yojoa, respectively (using the average values in Table 9.1). A number of limnological studies have shown that the M:D ratio often has a very significant effect on phytoplankton species composition (Wetzel 1983). Ratios below about 1.5 favor diatom growth, while higher values are favorable to desmids. (Note that the <u>ratio</u> of monovalent to divalent ions is the important factor, not absolute concentrations.) These general observations are supported by the phytoplankton studies carried out in L. Yure and L. de Yojoa. Diatoms (Bacillariophyceae) are rare in L. Yure but are an important component of the phytoplankton assemblage in L. de Yojoa. Desmids, however, are common in L. Yure, especially the planktonic genus <u>Cosmarium</u> and the benthic, filamentous genus <u>Desmidium</u>. In L. de Yojoa this group is rare, (Tables 7.15 and 8.6).

The M:D ratio of the El Cajón reservoir will probably be intermediate between those of L. Yure and L. de Yojoa. The ratio for the R. Humuya at El Cajón is about 0.4, which is higher than that for L. de Yojoa only because monovalent ion concentrations are higher in the river than in the lake. The M:D ratio for the R. Yure at the Humuya confluence averages about 0.7. These differences in the M:D ratio between the Yure and the Humuya/Sulaco rivers may not be sufficient to result in very distinct phytoplankton communities in the 3 main branches of the reservoir, but do represent a possible controlling factor to be considered in future studies of phytoplankton community structure.

9.5 PRIMARY PRODUCTION

The following comparative discussion of primary production (PPR) is divided into two parts. The first treats seasonal variation and annual production rates. The second discusses factors limiting photosynthesis.

9.5.1 Rates of photosynthesis

A summary of the productivity data for L. Yure and L. de Yojoa is presented in Table 9.1. Average daily rates of PPR have been calculated by dividing the annual production estimates (see Tables 7.10 and 8.5) by 365 days. The range of daily production rates in Table 9.1 refers to the range of values actually measured.

The similarity between the two lakes in the mean daily rates of PPR is striking, as is the relative difference between years. In L. Yure, the increased annual PPR in 1982 relative to 1981 is accounted for by a single, anomalously high production rate (Table 7.9). The measured PPR on 29/IV/82 was over twice the next highest value recorded in this lake. There are several reasons to believe that the data from this date are reliable; these are fully discussed in section 7.5. However, this sampling occasion may have represented the exponential growth phase of a major algal bloom and so using this data point to calculate average PPR rates to be included in an estimate of annual production is perhaps rather unrealistic. If one takes the PPR on 29/IV/82 to be the average of that measured on the two nearest dates (1990 mg c/m^2/day) then the total net annual production estimate for 1982 is decreased from

442.60 gC/m^2/year (Table 8.10) to 387.19 gC/m^2/year, a value very similar to that of the year before. The actual primary production in 1982 was probably somewhere between the two estimates.

In contrast to L. Yure, the increased 1982 production in L. de Yojoa resulted from higher measured rates of PPR during several periods in the year.

Although seasonal patterns of PPR were not fully consistent between years, there are some broad differences between the two lakes in the seasonal distribution of productivity. In L. Yure, total (areal) production rates are higher in the dry season (January-May), with P_{max} (highest productivity at any one depth) increasing from December to May as levels of solar radiation increase. The decrease in PPR during the wet season is attributable to higher levels of turbidity (primarily abiogenic) resulting from sediment loading from the inflowing streams. Secchi depths are lower at this time (Fig. 7.23), extinction coefficients are higher (Fig. 7.11) and suspended solids of the lake water have a lower organic matter content (Table 7.3a).

In L. de Yojoa, water clarity tends to decrease through the dry season and be higher from July to December. Both total and maximum rates of PPR appear to be positively correlated with full turnover events in December/January and on certain dates during the wet season when nutrients are re-introduced into the mixed zone. Internal (within-lake) recycling of nutrients is therefore more important in L. de Yojoa than in L. Yure, where the nutrient loading rate relative to the volume of the lake's euphotic zone is much greater.

Average photosynthetic efficiency is lower in L. Yure than in L. de Yojoa (Tables 7.2, Fig. 9.2) because of the higher abiogenic turbidity in the former lake during the wet season. The upper range of efficiencies is similar in both lakes, however. It should be noted that efficiencies have been calculated without taking into account non-photosynthetically active radiation and surface reflection. Incorporating these factors would probably approximately double the

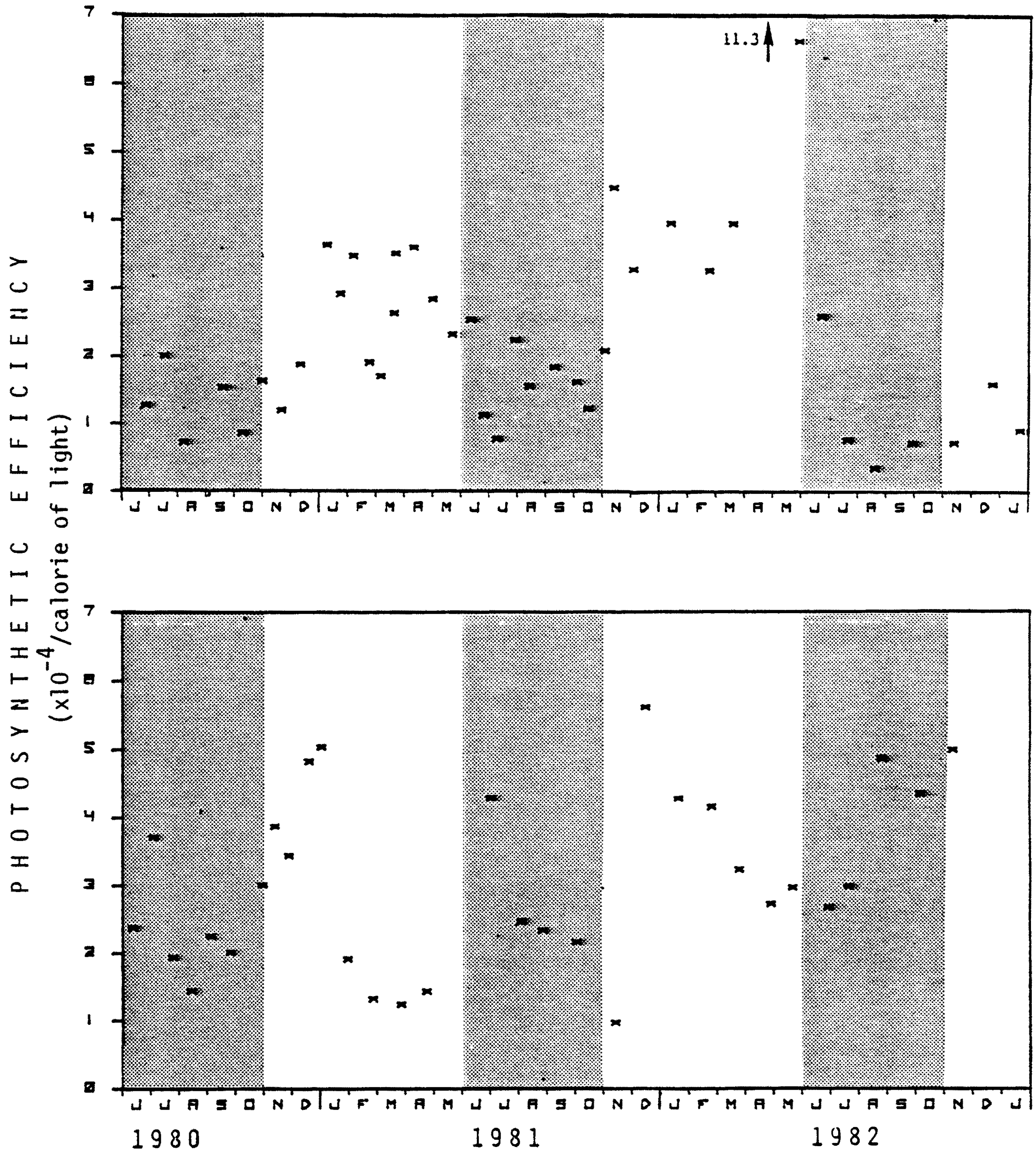


Figure 9.2: Seasonal variation in photosynthetic efficiency in (a) L. Yure and (b) L. de Yojoa. (The shaded areas represent the wet season).

Figura 9.2: Variación estacional en la eficiencia de fotosíntesis en (a) el L. Yure y (b) el L. de Yojoa. (La areas oscuras representan la estación lluviosa).

photosynthetic efficiency (e.g. Richerson _et al._ 1977).

The vertical distribution of photosynthesis shows clear differences between the two lakes. Measurable production often occurs to below 10 m in L. de Yojoa whereas in L. Yure there is usually little photosynthesis below 6 m. Subsurface PPR maxima are commonly observed in L. de Yojoa (Fig.8.6), since water clarity and high incident radiation result in surface inhibition of photosynthesis. Sub-surface maxima are less frequently seen in L. Yure, because higher epilimnetic turbidity reduces light penetration.

The effect of water transparency on the vertical distribution of PPR is further shown by comparison of mean values of total and maximum production (Table 9.1). Although the average daily rate of PPR (per m^2) is similar in both lakes, P_{max} is much lower in L. de Yojoa. Thus the similarity in the average areal productivity of these lakes results from an inverse relationship between PPR per unit volume of water and the depth to which significant production occurs.

Variation in P_{max} is similar in both lakes when expressed as a coefficient of variation (i.e. as a percentage of the mean value). The absolute range in P_{max}, however, is greater for L. Yure when data from the entire study period are considered. However, since L. Yure is a relatively new ecosystem which is still "developing", it is difficult to adequately characterize a mean annual variation in PPR for this lake.

In the new El Cajón reservoir, seasonal and depth variation in PPR will be more similar to that of L. Yure than L. de Yojoa. Epilimnetic turbidity will probably restrict photosynthesis to the upper 5-10 m of the water column during much of the year, especially between June and October. The depth of the euphotic zone will, however, depend on the depth at which river water moves through the lake. Not only would an epilimnetic flow increase abiogenic turbidity during the wet season, it would also increase nutrient supply to the epilimnion, thus stimulating primary production and increasing the level of biogenic turbidity. This is further discussed below.

Increased wind mixing during the wet season will increase the depth of the thermocline and reintroduce nutrients into the mixed zone. Whether or not this will lead to an increase in PPR (as seen in L. de Yojoa, for example.) will depend on the accompanying turbidity levels and the depth of the mixed vs. the euphotic zone (see below).

PPR will exhibit a significant amount of spatial heterogeneity in the El Cajón reservoir, especially during the wet season when sediment (and nutrient) loading is high. Further discussion of this is deferred to the end of the present section.

9.5.2 Factors limiting primary productivity

9.5.2.1 Light: When the euphotic zone of a lake is shallower than the mixed zone, algal cells are circulated to depths where they are temporarily deprived of light. Photosynthesis is thus light limited, since for a part of the day a proportion of the phytoplankton biomass is exposed to aphotic conditions. The extent of light limitation depends on the relative amount of time spent below the euphotic zone.

In both L. Yure and L. de Yojoa the depth of mixing is often greater than the depth of the euphotic zone. Fig. 9.1 illustrates the seasonal variation in these two parameters observed in both lakes. The greatest disparity between the mixed and euphotic zones occurs during the months of November to February. It should be noted however that, while a well-mixed epilimnion is usually observed in L. de Yojoa, the mixed zone in L. Yure is often much more difficult to characterize because of the development of secondary and diel themoclines as a result of strong surface heating and low wind stress (Fig. 7.7). For Fig. 9.1, designation of the mixed zone in L. Yure was made using both temperature and oxygen profiles. It probably overestimates the actual depth to which phytoplankton are mixed during much of the day. Therefore, the extent of light limitation may be overestimated for cells in the upper 1-2 m of the water column and underestimated for cells in the lower part of the epilimnion and metalimnion. (Note, however, that photoinhibition and even cell damage may be increased if cells are temporarily "trapped" in the warmer, surface layer [Goldman, Mason, and Wood 1963]).

Light limitation has been observed in a number of lakes, both natural and man-made (e.g. Lewis 1973, Viner 1973, Allanson and Hart 1975), and is likely to be of special importance in reservoirs which receive high loads of suspended sediments during the wet season (e.g. Kimmel and White 1979). Although photosynthesis must be light-limited when the mixed zone is deeper than the euphotic zone, the overall importance of light limitation to seasonal variation in primary production is often difficult to assess because of the variety of factors influencing photosynthetic activity. Deep mixing, for example, not only brings cells into aphotic conditions, but also reintroduces nutrients to the euphotic zone. Depending on a wide series of environmental variables, deep circulation may have opposite effects in different lakes. For example, a production maximum was observed for L. Victoria in East Africa, because mixing increased the supply of nutrients (Talling 1965). In L. Lanao (Philippines), however, mixing-induced light limitation resulted in a production minimum (Lewis 1974).

Light limitation during the wet season in the Humuya and Sulaco branches of the El Cajón reservoir will probably be more significant than it is in L. Yure, unless river inflow is always below the thermocline resulting in very little mixing with, and introduction of, abiogenic turbidity into the epilimnion.

Turbidity levels will often be quite high, especially in the upper reaches of the reservoir, and the greater wind fetch will result in a better mixed epilimnion relative to that commonly observed in L. Yure. Thus algal cells will probably be subjected to longer or more frequent periods of aphotic conditions.

The extent of light limitation will differ not only between the upper and lower reaches of the reservoir, but also between its major branches. The Yure branch will have less abiogenic turbidity, although this may be partially offset by higher phytoplankton densities at certain times of the year which would increase biogenic turbidity. Phytoplankton biomass, however, is unlikely to reach levels at which self-shading becomes important.

9.5.2.2 Nutrients: Nitrogen and phosphorus are the two nutrients which are most frequently observed to limit PPR in aquatic systems (Likens 1972). Tropical freshwaters have often been considered as usually nitrogen limited (Deevey 1957, Viner 1975a, Richerson et al. 1977). Various studies in Africa (e.g. Robarts and Southall 1977), South America (Zaret et al. 1981, Grobbelaar 1983) and India (Ganapati and Sreenivasan 1972) have supported this assertion. However, phosphorus (Halmann and Elgavish 1975, Melack et al. 1982) and iron (Robarts and Southall 1977) limitation have also been observed in tropical lakes.

As has been previously discussed (sections 6.2.8 and 7.4.4) the ratio of nitrogen to phosphorus in a lake and in its inflowing tributaries can provide an initial indication of whether production is more likely to be nitrogen or phosphorus limited. Bioassay experiments, however are the only way to adequately assess nutrient limitation and even these do not address the potentially significant factor of light limitation.

Before attempting to assess likely nutrient limitation in the El Cajón reservoir, two problems associated with N:P ratios must be mentioned. The first of these concerns the fraction of total phosphorus which is available to algae.

Significant amounts of PO_4-P are often adsorbed, or otherwise bound, to inorganic particulate matter, especially iron or aluminum-containing clays (section 6.2.7). A proportion of this PO_4-P can be utilized by algae (Golterman 1977, Viner 1982, Grobbelaar 1983). The importance of adsorbed PO_4-P to algal growth in lakes depends upon a number of factors, including ambient nutrient levels and mixing regime. The fact that algae can grow using sediments as their only phosphorus source and the ability of phytoplankton under certain conditions to utilize more complex forms of phosphorus than PO_4-P (Vincent 1981), demonstrate that neither total phosphorus nor PO_4-P concentrations accurately represent algal-available phosphorus.

The second problem associated with using river nutrient concentrations is that of estimating the actual supply rate of nutrients to phytoplankton in the euphotic zone. If density currents are common, a large proportion of the nutrients entering a reservoir may pass through the system without being entrained into the epilimnion, thus being effectively unavailable to the phytoplankton. For example, the underflow of a high phosphorus concentration density current in L. Mead (Nevada-Arizona, USA) means that much of the phosphorus input to the lake from the city of Las Vegas does not enter the euphotic zone and thus does not lead to the eutrophic conditions that would be predicted by the Vollenweider and Dillon (1974) phosphorus-loading model (Goldman 1976b.)

Thus the thermal regime of the El Cajón reservoir and the interactions between basin morphology, river inflow velocity and suspended sediment load will be crucial in determining the extent of mixing between epilimnetic and river water, and therefore nutrient concentrations in the euphotic zone. While, in the absence of a more extensive data-base (especially meteorological), it is not possible to precisely predict the thermal regime of the El Cajón reservoir and thus the depth of nutrient advection within the lake, the above discussion demonstrates that a detailed monitoring of inflow characteristics will be essential for obtaining an adequate understanding of the production processes occurring within the new reservoir (See Appendix 7).

Average inorganic nitrogen:total phosphorus ratios for the three main tributaries of L. Yure were between 8 and 15, but variation within each stream was high (Table 6.3). The N:P ratios for L. Yure and L. de Yojoa were similar (mean values 8.4 and 8.9 respectively). The stream ratios would indicate phosphorus limitation for L. Yure (especially at the index station, which is influenced primarily by Q. Sin Nombre and Q. del Cerro, the streams which exhibit the higher N:P ratios). The ratios observed in the lake itself would suggest either nitrogen or phosphorus limitation. In fact, during both the wet and dry seasons of 1981-82, phytoplankton growth was shown to be limited by phosphorus and, secondarily, iron (Fig. 7.24). Phosphorus apparently also limits primary production in L. de Yojoa.

The N:P ratios of all the major rivers flowing into the El Cajón reservoir are lower than those of the L. Yure tributaries (Table 6.3). The R. Humuya at the Sulaco confluence for example exhibited a mean ratio 1.3($\pm$1.0), (and a N:PO_4-P ratio of 2.9($\pm$1.4)). These ratios, by themselves, suggest that all three major branches of the reservoir will, unlike L. Yure, be nitrogen limited. N:P ratios will in addition be influenced by nutrients leached from reservoir basin soils and flooded vegetation. However, based on leaf leaching experiments carried out in L. Yure (Knud-Hansen 1983), nutrient release from vegetation is likely to be characterized by N:P ratios even lower than those of the river water i.e. <0.5.

It is difficult to predict the extent of possible iron limitation in the El Cajón reservoir, but high loading rates of iron (albeit mainly in the particulate form) suggest that it may well be less significant than it is for the L. Yure system. The dynamics of iron in lake systems is complex, however. Not only is the fraction of total iron available for algal growth unknown (Shapiro 1966), chelation with organic compounds may either decrease (Giesy 1976) or possibly increase (Viner 1975b) the supply of iron for the phytoplankton.

9.6 PLANKTON

The phytoplankton communities of L. Yure and L. de Yojoa are very different from each other. Blue-green algae (Cyanophyta) and, to a lesser degree diatoms (Bacillariophyceae), dominate in L. de Yojoa, both in terms of numbers and biomass. In L. Yure, small green flagellates and desmids are dominant. The possible influence of the monovalent:divalent ion ratio on species composition has already been discussed (9.4).

Many species of blue-green algae can fix molecular nitrogen and are often common in lakes which exhibit low concentrations of inorganic nitrogen. Under these conditions they can compete successfully with other algal species which are limited by low nitrogen levels. The common blue-greens in L. de Yojoa, however, lack heterocysts and are not nitrogen fixers.

The composition of phytoplankton communities is determined by a wide variety of factors which influence species-specific rates of cell loss (e.g. sinking, herbivory by zooplankton, flushing from the system in the case of reservoirs with a retention time of less than a few days) and growth (e.g. nutrient levels, light). During the present study there was no opportunity to examine any of these factors in sufficient detail to allow an assessment of the relative importance of each of them in the population dynamics of individual species. It is not possible, therefore, to predict algal species composition in the El Cajón reservoir. Future monitoring of phytoplankton populations, however, will enable a better insight to be gained into patterns of productivity in the new lake.

A number of studies on tropical zooplankton communities (e.g. Twombly 1983) have demonstrated a considerable amount of temporal variation in community structure, both within and between years. Significant variability was also evident in the Yure and Yojoa zooplankton communities. The assemblages were very different from each other during most of the period occupied by this study. The only common species which were found in both lakes, were the rotifers *Filinia* and *Keratella*. The large number of rotifer species and high density of individuals in L. Yure was quite different from the situation in L. de Yojoa, where only two species were abundant. Total rotifer density was lower in L. de Yojoa, but cladocean densities were generally similar in both lakes. Copepod biomass was almost certainly higher in L. de Yojoa than in L. Yure because of the presence in the former lake of the medium-sized genus *Diaptomus*. However, the absence of biomass data for L. de Yojoa means that it is not possible to fully compare the plankton communities of these two lakes. The similarity in mean daily primary production between the two lakes may suggest a similarity in zooplankton production. No data exist on secondary production, however, and it should be noted that a large fraction of pelagic primary production in L. de Yojoa is probably unavailable to zooplankton (i.e. the colonial *Microcystis*).

In 1982, after the invasion of *Daphnia* into L. Yure, zooplankton communities in both lakes resembled each other to a greater degree than before. Cladoceran dominance by *Daphnia* and the presence of only one or two species of abundant rotifers are characteristics now shared by both lakes.

As with phytoplankton, the factors controlling zooplankton communities are too diverse to enable an adequate prediction of species composition in the El Cajón reservoir. The importance of zooplankton to the production processes occurring in a lake have been discussed previously (section 7.8). Perhaps the most "obvious" illustration of zooplankton importance is as a food source for fish. The influence of L. Yure zooplankton species composition on fish diets is discussed in section 11. Usually, there is a two-way interaction between fish and zooplankton, with the latter providing food for the former and zooplankton community structure being influenced by fish feeding selectivity (Hrbácek et al. 1961, Brooks and Dodson 1965, Hall et al. 1976, Zaret and Suffern 1976). Since zooplankton constitute the major food source for fish such as bass juveniles (Micropterus salmoides) and Astyanax fasciatus (the latter representing an important diet component for adult bass), an effective fish management program for the El Cajón reservoir will require a knowledge of zooplankton population dynamics. This is especially so if pelagic fish species (Melaniris guatemalensis, for example) attain importance in the new reservoir (see, further, sections 3 and 11).

9.7 BENTHIC INVERTEBRATES

The most important food source for fish in the El Cajón area is benthic invertebrates, primarily insect larvae. In L. Yure, invertebrate densities were very low until 1982 and were represented principally by chironomids. The scarcity of benthic invertebrates in the reservoir was reflected in fish diets; stomach contents often consisted mainly of silt, plus a few chironomid larvae.

The gradual development of rooted macrophytes around the shore-line of L. Yure, and especially the increase in population of benthic filamentous algae and the macroalga Chara (Fig.7.4) resulted in increasing densities of invertebrates. Dragon-fly larvae of the anisopteran genus Idiataphe became especially common and probably constitute the food base of the bass population in this lake (as anisopteran larvae also do for the bass of L. de Yojoa). Several mayfly species are also now common in L. Yure as well as two genera of molluscs, Physa and

Goniobasis. The snails have become important diet components for the only cichlid in L. Yure, Cichlasoma montaguense ("guapote"). An additional mollusc now present in L. Yure, and one seasonally common in L. de Yojoa, is Biomphalaria. This genus (although not necessarily the same species) is a vector for schistosomiasis in various parts of the world. It was originally intended for scientists from the Smithsonian Institution in Washington D.C. to conduct host compatibility studies with Biomphalaria from L. de Yojoa, and snails were collected for this project by personnel from the Santa Cruz laboratory. The study was apparently abandoned, however, for reasons which were not entirely clear. Because of the potential importance of this host it would be advisable to consider re-activating this study in the near future.

In a number of reservoirs flooded trees provide an important substrate for periphyton and insect larvae. In the Volta lake (Ghana), for example, a burrowing mayfly, Povilla colonized flooded trees and formed the major food base for the reservoir's developing fishery (Petr 1970). Most of the trees in the L. Yure basin were felled before inundation, but a number remain in one area of the reservoir. Colonization by invertebrates, however, has never been significant, probably because the wood is too hard. However the trees do provide important emergence "routes" for Idiataphe adults.

The benthic fauna of L. El Cajón will gradually develop in parallel with macrophytes, as is discussed below. Reservoir morphology and drawdown regime strongly suggest that rooted macrophytes, and thus benthic invertebrates, will not attain high densities in many parts of the lake. Therefore zooplankton will represent a potentially more important food source. The drawdown characteristics of the reservoir will probably further act directly to reduce invertebrate densities.

9.8 MACROPHYTES

Differences between the macrophyte/macroalgal communities of L. Yure and L. de Yojoa result primarily from the distinct morphologies of the lakes and the age of L. Yure. Extensive infestations of the water hyacinth *Eichhornia crassipes* occur in L. de Yojoa, principally at the southern end of the lake in an area of flooded forest. Such areas often encourage the formation of large mats of floating plants by forming "anchors" which counteract the disruptive effect of wind. In L. Kariba, for example, the water fern *Salvinia* was absent in areas from which trees had previously been cleared (McLachlan 1969). *Eichhornia* has so far not been recorded from L. Yure, but its accidental introduction would be a relatively easy matter.

Vegetation clearance in the El Cajón basin will have significantly reduced the chance of large infestations of floating macrophytes occurring. However this is not intended to imply that colonization will not take place at all, especially in the more sheltered embayments of the reservoir. Introduction of *Eichhornia* is very likely from upstream areas around Comayagua where this plant has been observed. Potential problems associated with extensive infestations of floating aquatic plants have been summarized in Vol. 5 of the El Cajón feasibility study (Goldman 1972) and in numerous other scientific publications and do not require further review here. A detailed prediction of the extent of development of floating macrophyte populations in the El Cajón reservoir is not possible, given the variety of interrelated factors which influence these plants. However, the possibility for significant invasion is sufficiently high that routine patrols should be made around the new reservoir, in order to eliminate any developing populations of potentially nuisance species. Such patrols could carry herbicide spray units and easily be integrated with a program for synoptic limnological sampling in the lake (see section 3). The importance of preventing infestation before it takes hold cannot be overemphasized.

Development of populations of rooted aquatic macrophytes will take from 3 to 6 years, based on the experience of L. Yure and other tropical reservoirs (e.g. McLachlan 1969). Growth of rooted plants will be influenced by such factors as slope of the littoral area and extent of drawdown as well as the degree of shading from biogenic and abiogenic turbidity (Barko 1981). As mentioned in the previous section, the establishment of benthic plants will have a significant positive effect on invertebrate densities and thence on fish populations and, further, will help stabilize the shoreline along the wave-zone of the lake.

9.9 CONCLUSIONS

Section 9 has attempted to provide a broad, comparative review of much of the limnological data presented and discussed in sections 6-8. In doing so, information obtained from comparative studies on L. Yure and L. de Yojoa has been used to extend the data-base of the river water quality monitoring program into a discussion of some important aspects of the probable limnology of the El Cajón reservoir. It is obvious from this discussion that many questions remain about the functioning of the Yure, Yojoa and El Cajón systems. A number of these questions have been emphasized in the preceding discussion since it is felt that they represent areas which particularly merit future investment of research effort. The goal is a better understanding of the El Cajón ecosystem, with the view of establishing rational and effective management programs for this and future reservoirs in Honduras and throughout the tropics in general.

The El Cajón reservoir will, in effect, be three rather separate ecosystems, corresponding to the valleys of the three major tributaries.

Because of its dendritic morphology, spatial heterogeneity in the system is likely to be relatively high. This will complicate any attempt to characterize the reservoir's limnology, but at the same time it will offer considerable opportunity for further investigating many of the interacting factors which, as discussed above, will influence water quality and the biota.

There will be two major components to the spatial heterogeneity observed in the reservoir. The first of these relates to differences between the three main branches. The Humuya and Sulaco branches will probably be similar since river valley morphology and water chemistry are similar. The Yure branch will have a low suspended sediment loading and reduced abiogenic turbidity may well result in a somewhat deeper thermocline and euphotic zone, as discussed previously. Inorganic nitrogen loading per unit area of lake will be similar in the Yure and Humuya branches since NO_3-N concentrations are approximately the same in both rivers and the lower surface area of the Yure branch partially compensates for the lower discharge rates of the R. Yure. Total phosphorus loading per unit area of the Yure branch will, however, be lower than that for the Humuya and Sulaco branches because of the lower sediment concentrations of the R. Yure. It appears probable that N:P ratios below 8:1 will exist throughout the reservoir, suggesting nitrogen limitation.

Variation in primary production between the branches will depend on differences in turbidity, the depth of the mixed *versus* euphotic zones and the degree of entrainment of river water into the epilimnion. The more constant discharge of the R. Yure relative to the Humuya and Sulaco rivers suggests that the Yure branch will exhibit a greater temporal stability of water quality and productivity parameters. Differences in the ionic composition of R. Yure water, however, may well lead to a divergence in phytoplankton species composition (and thus possibly also zooplankton species composition) relative to the communities of the Humuya and Sulaco branches.

The second major component of spatial heterogeneity will be a longitudinal one, i.e. on a gradient from the inflowing rivers to the dam wall. Kimmel (1981) has described four phases of phytoplankton response to turbid inflows. Although this sequence specifically considers responses to a major storm event (i.e. temporal heterogeneity), it applies equivalently to patterns of longitudinal variation. In terms of spatial variation, the sequence is as follows:

1. In the well-mixed upper reaches of the reservoir, turbid inflowing water reduces light penetration and thus primary production is light-limited.
2. Algal cells are advected from the zone of river inflow during storm events. In the dry season, phytoplankton species characteristic of a riverine environment are replaced by (usually smaller) lacustrine species.
3. In the transition zone, which usually starts at about the plunge point, much of the suspended solids load settles out, allowing greater light penetration. Nutrient concentrations are also higher in this zone because of the proximity of the river inflow. The combination of high light and nutrient levels results in a stimulation of primary production. Production rates (per unit volume of water) are usually highest in this region but, as discussed above, they will depend on the extent of nutrient entrainment into the euphotic zone.
4. In the lower reaches of the reservoir, light penetration tends to increase further as more suspended material settles out. Nutrients become increasingly incorporated into living organisms which, as they sink into the hypolimnion, transport a proportion of the nutrients out of the mixed zone. Nutrient recycling within the epilimnion thus becomes increasingly important in the lower reaches of the lake. Total (areal) primary

production may be similar in both upper and lower reaches, since increasing euphotic depth towards the dam wall compensates for the reduction in productivity per unit volume of water which results from decreased nutrient concentrations.

When this generalized pattern of longitudinal variation is superimposed on the variation between the major reservoir branches and the temporal variation resulting from individual storm events and changes in depth of river water flow, it becomes clear that the El Cajón reservoir will be a very complex ecosystem and a great and exciting challange to the limnologist. A carefully designed monitoring program will be needed to further relate the already existing extensive data base to a detailed characterization of the new reservoir's limnology. The most effective management procedures for vector control, higher plants, and fisheries development may need to be specifically tailored for the individual reservoir arms. The recommendations for the main components of such a program are set forth in section 3.

10.1 INTRODUCTION

In this section, the results of a small monitoring study on the invertebrate fauna of Quebrada El Cajón are presented. This study did not constitute a major part of the Limnology and Fisheries Program; it was designed primarily to provide an initial descriptive account of seasonal patterns in the composition of the invertebrate community. Aquatic insect larvae form the food base for a large proportion of riverine fish species. An understanding of invertebrate community structure and dynamics therefore forms an integral part of studies on the trophic ecology of fish. This area is further discussed in section 11. As was previously mentioned (see section 4.2.2), an adequate characterization of stream invertebrate biomass demands an intensive study because of spatial heterogeneity (and sampling variance) in the community. While the data discussed here do not represent absolute biomass or density values, they can be used as a comparative measure of abundance.

The complete invertebrate data set is provided in Appendix 5. Table 10.1 summarizes these data by grouping the insect genera into their respective families. A further summary of the data is provided by Table 10.2 which presents four aspects of community diversity. The first two of these (number of taxa and number of animals/5 min. sample) are self-explanatory. H′, the Shannon-Weiner diversity index, is a compound index summarizing both the total number of species and the relative dominance of individual species. Higher values of the index indicate higher species diversities. J is an equitability index and describes the "evenness" component of diversity, i.e. the abundance of species relative to each other. (Thus a community consisting of 10 species, with each species being represented by 20 individuals, is more "even" or "uniform" than a community consisting of 1 species represented by 182

Table 10.1: Seasonal variation in the composition of the insect community of Q. El Cajón. (Data represent mean number of individuals/5 min. sample as a percentage of mean total number of animals/5 min. sample for that date).

Tabla 10.1: Variación estacional en la composición de la comunidad de insectos en la quebrada El Cajón. (Los datos se refieren al número promedio de individuos por muestra de 5 minutos como un porcentaje del número total de animales atrapados en la fecha).

Order	Family	1979 24/VIII	27/IX	9/XI	30/XI	14/XII	27/XII	1980 10/I	24/I	22/II	21/III	10/IV	22/V	6/VI	20/VI	18/VII	14/VIII	27/VIII	25/IX	29/X
DIPTERA	Simuliidae	22.7	21.7	2.8	0.9	0.8			0.6						20.1	1.9				
	Chironomidae	0.4	0.7	2.2	1.8	1.7	2.8	7.5	6.1	1.8		22.0			6.8				1.1	0.7
	Psychodidae	2.1	0.7	2.2	4.4	6.0	0.7		8.5								0.7			0.7
	Dixidae			1.1					0.6											
	Stratiomyidae									0.9										
	Empididae					0.8														
	Tipulidae	0.4																		
	?								3.6									1.3		
MEGALOPTERA	Corydalidae	1.2		0.5	1.8	1.7			1.8		1.0		1.3					1.3	1.1	1.4
TRICHOPTERA	Hydropsychidae	1.7	7.2	2.8	8.0			3.8	3.1	5.3	2.0		1.3			0.6	4.1	1.3	3.3	4.8
	Hydroptilidae	9.1	0.7	25.9	2.7	11.2	0.7	23.7	4.3	17.6	34.8	1.7	1.3				1.3		1.1	7.5
	Leptoceridae						0.7		0.6		1.0									
	Helicopsychidae		0.7	0.5	0.9		0.7	1.2	3.1	0.9	3.9		1.3	5.2						
	Glossosomatidae					0.8			1.8											
	Psychomyidae								0.6											
	Polycentropidae					0.8							1.4							
	Calamoceratidae																			
	Philopotomidae		2.9							0.9		1.7	3.8							
	?			2.2	1.8	0.8	3.5		4.3	8.8	1.0		1.3	0.5			2.7			
EPHEMEROPTERA	Baetidae	47.5	29.0	25.3	35.4	26.7	41.0	37.5	18.8	2.7	1.0				6.8	91.0	71.6	30.6	63.8	44.6
	Leptophlebidae	4.1	1.4	2.2	2.7	14.7	7.0	2.5		0.9	3.9	3.4	1.3				2.0	1.3	5.5	2.7
	Tricorythidae	0.4	2.2	10.1	4.4	7.8	11.1	8.7	12.1	8.8	3.9	17.0	12.4		13.3	1.3	3.4	3.9	3.3	10.3
	Ephemeridae	4.1	6.5	2.8	22.1		14.6	2.5	9.7	7.0	12.9	1.7	9.9			0.6	3.4	20.4	14.3	
	Caenidae	0.4	0.7	0.5						0.9		11.9	2.5	7.7	5.6					15.1
	?					5.2			0.6							0.6	0.7			

Table 10.1 (cont.)

Order	Family	1979 24/VIII	27/IX	9/XI	30/XI	14/XII	27/XII	1980 10/I	24/I	22/II	21/III	10/IV	22/V	6/VI	20/VI	18/VII	14/VIII	27/VIII	25/IX	29/X
COLEOPTERA	Psephenidae	1.7	7.2	1.7	4.4	4.3		2.5	6.7	6.2	8.0	13.5	27.2	51.3	6.8		5.4	20.4	2.2	2.7
	Elmidae	0.4	1.7	3.4		11.2	4.9			13.2	5.0		22.3	2.5		1.3	0.7	2.6		6.1
	Staphylinidae			0.5																
	? (larvae)								0.6		1.0		1.3	2.3	26.7					1.4
	? (adults)				2.7				3.6	0.9	2.9									
HEMIPTERA	Veliidae	2.5		4.5		0.8	8.3	2.5		8.0	3.9	20.3	1.3			0.6	3.4	1.3		
	Naucoridae	0.4		0.5					0.6				1.3		6.8			1.9		
	Belostomatidae			0.5																
	Hydrometridae										2.0									
ODONATA	Coenagriidae	0.4	6.5	1.7	0.9	1.7	2.1	2.5	1.8	0.9	6.0	1.7	5.0	10.2	6.8	1.9	0.7	11.5	4.4	0.7
	Agriidae									0.9										
	Libellulidae			1.1			0.7		1.2	2.7	2.9									
	Corduliidae				0.9		0.7													
	Gomphidae										1.0									
	?				0.9			3.8		0.9			2.5	7.7				1.3		0.7
PLECOPTERA	Perlidae		5.8	1.7	2.7					3.5		1.7	1.3					1.3		
	?								3.1											
LEPIDOPTERA	Pyralidae		0.7	2.2	0.9	3.4		1.2	1.8	6.2	2.0	3.4		7.7						0.7

Table 10.2: Characteristics of the invertebrate community of Quebrada El Cajón, November 1979 - October 1980.

Tabla 10.2: Características de la comunidad de invertebrados en la quebrada El Cajón, noviembre 1979 a octubre 1980.

Date	Mean # taxa/ 5 min. sample	Mean # animals/ 5 min. sample	H'*	J*
9-XI-79	6.1 (2.7)	15.0 (11.3)	1.36	.89
30-XI-79	6.9 (2.7)	15.6 (6.1)	1.11	.79
14-XII-79	7.0 (4.1)	16.3 (12.1)	1.19	.88
27-XII-79	7.3 (2.1)	20.3 (8.8)	.99	.74
10-I-80	4.0 (2.6)	11.4 (12.6)	1.04	.84
24-I-80	8.6 (3.0)	18.9 (8.2)	1.33	.86
22-II-80	8.4 (4.0)	14.5 (6.0)	1.34	.90
21-III-80	5.4 (2.7)	10.7 (7.3)	1.17	.83
10-IV-80	4.0 (1.3)	9.5 (4.7)	1.03	.86
22-V-80	5.4 (2.1)	9.9 (6.7)	1.08	.80
6-VI-80	2.4 (1.0)	5.4 (3.5)	.70	.73
20-VI-80	2.2 (1.0)	3.0 (1.8)	.84	.93
18-VII-80	3.8 (1.6)	30.6 (31.6)	.61	.58
14-VIII-80	5.2 (1.2)	24.7 (19.0)	.79	.65
27-VIII-80	4.4 (1.2)	9.8 (3.8)	1.03	.86
25-IX-80	4.7 (1.3)	13.0 (8.1)	.86	.77
29-X-80	7.0 (1.5)	20.9 (9.7)	1.01	.78

* H' = Shannon-Weiner diversity index = $-\sum^{i} p_i \ln p_i$

J = Equitability index = H'/ln S

where p_i = proportional abundance of species i

S = total number of species

and ln = natural logarithm

individuals and the other 9 species being represented by 2 individuals each. Note that the total number of species and individuals are the same in each "community".)

The number of taxa (not all forms could be identified to the genus level) per 5 minute sample varied from 2.2 to 8.6. Standard deviations usually were about 50% of the mean. More species were present in the samples between November and February than during the rest of the year. Total numbers of individuals were also generally higher in the dry season, although large numbers of Ephemeroptera (Baetis, Dactylobaetis and Baetodes) were collected in July and August. These genera are characteristic fast-water forms.

Species diversity, H′, was higher between November and March, and declined with total invertebrate densities at the beginning of the wet season. Community "evenness", J, was similar throughout the year, except in July and August when mayflies (Ephemeroptera) strongly dominated the community.

The seasonal pattern of invertebrate abundance encountered in Q. El Cajón is commonly observed in running waters. Reduced flows and turbidity levels in the dry season, together with a greater development of periphyton (attached algae), provide a more suitable environment for most aquatic insects than the wet season does. Predation pressure, however, can increase in the dry season and this, combined with larval maturation and subsequent emergence as the adult stage, often leads to a reduction in larval numbers during the latter part of the dry season. For example, suspended sediment concentrations in Q. El Cajón on 6/VI/80 were very high (296 mg/l - see Table A2.9), indicating flood conditions. On the same date, the number of animals and the number of taxa per sample decreased to about 50% of previous values. Numbers remained low on 20/VI/80, when the water was still turbid, but increased from July onwards when the water cleared.

Of the 36+ families represented in the Q. El Cajón invertebrate community, only a few were ever abundant. Fig. 10.1 summarizes in a general way those months when the major species were present in the stream. A species was considered absent if it was not collected on two or more consecutive sampling occasions. Baetis, Dactylobaetis and Baetodes were among the most common genera, but were present primarily from July to December. They frequently represented over 40% of total invertebrate numbers. The two other common Ephemeroptera were Leptohyphes and Thraulodes. The former was most abundant between October and May, the latter between August and April.

The only genus to remain common during the June flood was the beetle larva, Psephenus. It has a very flattened body form and thus is well adapted to withstand flood conditions. Elmidae larvae represented a significant component of total insect numbers on a few dates, but individual genera were usually uncommon.

The damselfly Argia (Coenagriidae) was present through much of the year, but was never common. Dragonfly (Anisoptera) genera were only occasionally collected (in contrast to the situation in L. Yure and L. de Yojoa, where they are important biomass components). Stoneflies (Plecoptera) were also rare in this stream

10.2 TROPHIC RELATIONSHIPS

Insect taxa were assigned to one of eight feeding mechanisms according to the classification of Merritt and Cummins (1978). Where these authors listed more than one feeding mechanism for a genus, the most common method was assumed (i.e. the first in the list). Categories are summarized at the foot of Table 10.3, which presents the percentage of individuals using each feeding mechanism for the 17 sampling dates. The data in this table clearly show that scrapers (periphyton grazers) and collectors-gatherers (detritivores) were the feeding

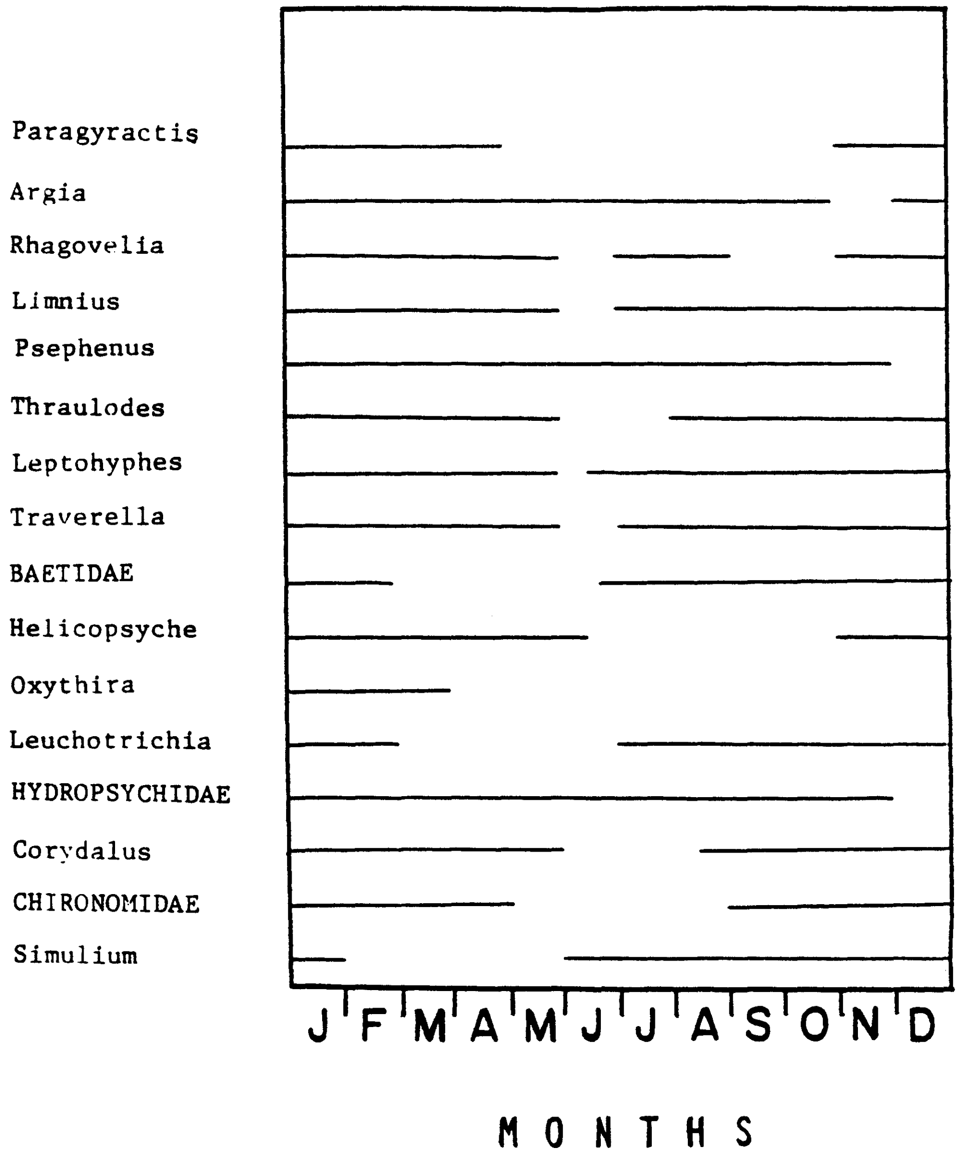


Figure 10.1: Diagram to show the months when various insect taxa were present in Q. El Cajón. (Bars indicate presence in the stream).

Figura 10.1: Diagrama para señalar los meses cuando varios géneros y familias de insectos fueron encontrados en la quebrada El Cajón. (Las líneas indican la presencia de un género en la quebrada).

Table 10.3: Classification of the Q. El Cajoń aquatic insect community on the basis of feeding mechanism. (Data are % of total number of animals collected on a sampling date).

Tabla 10.3: Clasificacioń de la comunidad de insectos en la quebrada El Cajoń, basándose en la forma de alimentacioń. (Los datos representan el porcentaje del número total de los animales colectados en la fecha del muestreo).

Date	Feeding Mechanism*								
	S	C-f	C-g	E	P-h	P-c	S-d	S-h	U/K
1979									
9/XI	30	7	37	5	10	6	0	2	4
30/XI	34	11	43	6	1	0	0	1	5
14/XII	38	8	40	4	0	1	0	3	6
27/XII	34	7	43	3	1	8	0	1	4
1980									
10/I	57	6	22	3	7	3	0	0	3
24/I	33	4	35	8	2	2	0	2	14
22/II	11	6	37	8	13	8	1	6	10
21/III	23	5	20	9	33	5	0	2	5
10/IV	13	5	51	4	2	20	0	3	3
22/V	27	8	45	11	1	2	0	0	6
6/VI	58	0	9	18	0	0	0	7	7
20/VI	7	26	26	7	0	7	0	0	26
18/VII	67	5	25	2	0	1	0	0	1
14/XIII	80	3	9	1	0	3	0	0	4
27/XIII	44	5	32	16	0	2	0	0	1
25/IX	54	12	29	5	0	0	0	0	0
29/X	48	3	44	3	0	0	0	0	2

* S = Scrapers (periphyton feeders = herbivores)
C-f = Collectors-filterers (suspension feeders = detritivores)
C-g = Collector-gatherers (sediment feeders = detritivores)
E = Engulfers (predators)
P-h = Piercers-herbivores (suck fluids from plants)
P-c = Piercers-carnivores (suck fluids from animals)
S-d = Shredders-detritivores (chew detritus)
S-h = Shredders-herbivores (chew living plant material)
U/K = Unknown feeding mechanism (s)

(note: percentages do not sum to exactly 100% on some dates - this is because of rounding errors) mechanisms used by a majority of the individuals sampled. There was no clear pattern of seasonal variation in the relative importance of various trophic categories, although some were well represented on only a few sampling dates (e.g. piercers-herbivores). Predators represented between 1 and 18% of total individuals, and averaged about 7%.

The main predators in this stream were Elmidae larvae, Odonata and Plecoptera. The most common filter-feeders were *Simulium*, the Polycentropidae and *Traverella*. Important collector-gathers were the Hydroptilidae and especially the Ephemeroptera, with the exception of *Dactylobaetis* and *Baetodes* which are primarily scrapers. The Hemiptera were the only carnivorous piercers.

SIMULIUM AND ONCHOCERCIASIS

Black-fly larvae were recorded principally during the wet season. They are typically associated with fast-flowing water and can be important disease vectors in the tropics (Stanley and Alpers 1975). Individuals collected in August and September 1979 were probably *S. jobbinsi* and *S. metalicum*, (D. Abell, pers. comm.), but species identifications are uncertain without examination of the adult stages. A third species, probably *S. ochraceum*, was also collected from Q. El Cajón.

Two of these species are known to be vectors of onchocerciasis. *S. ochraceum* is the primary vector in areas with many small streams in Guatemala, whereas *S. metallicum* is important where larger rivers are present. Additional collecting from other streams in the El Cajón area would almost certainly reveal the presence of *S. callidum*. This species is also a vector of onchocerciasis and is usually found in forested areas. A further species, *S. exiguum*, breeds in rivers at levels below those at which other species are common. Since it is present both to the north and to the south of Honduras, it is probably also present within, or near, the El Cajón area. Particular attention should be given to its future distribution in Honduras.

Reduction in the sediment load of water released from the El Cajón reservoir will greatly improve the habitat for blackflies in the region below the dam, and control measures may be necessary.

Simulium can complete a breeding cycle in a little over three weeks. However, since larvae cannot survive even short periods of drying (though pupae can), it is possible to control simuliid populations by managing the release of water from dam spillways. This has been practiced, to good effect, in a number of hydroelectric projects (for example, the Akosombo dam on the Volta River in Ghana, Petr 1970).

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