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DEVELOPMENT OF AN INTEGRATED ECOLOGICAL RESEARCH PROGRAM FOR THE PARANA RIVER IN ARGENTINA

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ABSTRACT

Lugo, A.E.; M.M. Brinson and S.Brown. 1986. Development of an integrated ecological research program for the Paraná river in Argentina. *Rev. Asoc. Cienc. Nat. Litoral, 17* (2): 137 – 155.

Regional and individual ecosystem models are used as tools for organizing researchers to answer questions about the environmental impacts of construction of a power-generating dam on the ecosystems of the Rio Parana Basin. Critical research questions are formulated in five subject areas derived from the models. These subject areas are: hydrology, material storages and fluxes (e.g., carbon, sediments, nutrients), consumer communities (e.g., fish, birds, other animals), impacts outside the project area, and mitigation. The advantages of the proposed holistic approach to research in the Paraná River Basin are discussed and suggestions are given for planning, executing, promulgating, and implementing research programs.

RESUMEN

Lugo, A.E.: M.M. Brinson y S. Brown. 1986. Desarrollo de un programa integral de investigaciones ecológicas para el río Paraná en Argentina. *Rev. Asoc. Cienc. Nat. Litoral, 17* (2) : 137 – 155.

Grandes proyectos de desarrollo conllevan impactos ambientales que se manifiestan a escalas poco estudiadas en la ecología. La planificación y ejecución de investigaciones que provean información sobre los impactos de tales proyectos constituyen un reto a los investigadores y a las organizaciones responsables por la salud del medio ambiente. Para facilitar esta tarea se presentan modelos de ecosistemas y de regiones los cuales son útiles para organizar esfuerzos interdisciplinarios como los que se están llevando a cabo en la cuenca del Río Paraná para evaluar los impactos de una represa en el Paraná Medio. Partiendo de los modelos se formulan preguntas o hipótesis de investigación en cinco áreas específicas. Estas son: hidrología, almacenaje y movimiento de materia (p. ej., carbono, sedimentos, nutrientes), comunidades de consumidores (peces, aves, otros animales), impactos fuera del área del proyecto, y mitigación de daños. Se presentan además sugerencias para planificar, organizar, y ejecutar las investigaciones y para promulgar e implementar sus resultados. Las ventajas de enfoques holísticos a las investigaciones ecológicas se discuten a la luz de proyectos como el del Paraná Medio.

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INTRODUCTION

Large-scale development projects that alter the movement of water through ecosystems have the potential for creating profound ecological changes. To assess and predict the consequences of these impacts, it is necessary to conduct ecological studies and evaluate the results in a manner that recognizes the scale of the changes. An example of a large-scale project in Argentina is the construction of power-generating dams and turbines in the middle reach of the Paraná River. In this paper we outline a research plan that can be used to evaluate the environmental consequences of such a project. Although the plan is discussed with the Middle Paraná River in mind, the approach that we outline could be applied to large-scale projects elsewhere in the world.

The plan is based on information that we gathered from aerial reconnaissance of the area, discussions with scientists and engineers related to the project, and reading research reports. This paper is organized into the following sections which outline an integrated and comprehensive program for research in the Paraná Basin.

– Conceptual model of wetland ecosystem structure and function. In this section we discuss the use of an ecosystem model to plan and integrate research projects.

– Hierarchical scheme of ecosystems in the Paraná River Basin. Here we provide guidelines for establishing the levels of biological complexity at which ecosystem studies can be conducted.

– Critical research questions. This section presents questions that are arranged into six subject areas, derived directly from the ecosystem model, that required attention at the time of our review.

– Organization of manpower. The final section contains a suggested scheme for planning, executing, promulgating, and implementing research programs.

During our visit (about 4 days) we were not asked to evaluate the pros and cons of the Middle Paraná project and we will not express our views on its economic and ecological feasibility. Therefore, the formulation of this plan should not be construed as an endorsement of the project.

DESCRIPTION OF PROJECT AREA

The Paraná River has a drainage basin of 2.0×10^6 km^2 and is the second largest drainage basin in South America. The project addressed in this paper is the middle reach located in Argentina between Corrientes, where the Paraguay River and Upper Paraná Rivers converge (27° 16′ S. Lat.; 58° 36′ W. Long), and the island of Chapeton (31° 33′ S. Lat.; 60° 18′ W. Long.) near Santa Fe. Along this 490-km sector, known as the Middle Paraná, inflow from tributaries is minor in comparison with discharge of the main river channel. At low discharge, flow is confined to a series of channels that are located mostly along the eastern margin of the 30 to 35 km-wide floodplain. Maximum flooding normally occurs in February and inundates much of the floodplain with 2 to 3 m of water depth. At low stage, the floodplain is occupied by palm swamps in the warmer climate to the north and by woody dictolydenous trees and shrubs in the south. Numerous depressions in the floodplain retain water during low stage, many of which are isolated from the river channel. These lagoons support submersed, floating, and emergent aquatic macrophyte communities.

The dam for hydroelectric power generation being constructed at El Chapeton will be high enough to potentially back up water approximately 200 km to the site of a second proposed dam near Reconquista. This second dam would likewise back up water near Corrientes, about 220 km above Reconquista. Physical, chemical and biological characteristics of the Middle Paraná River were summarized by Bonetto *et al*[1].

CONCEPTUAL MODEL OF WETLANDS

Any research plan designed to answer questions about the structure and function of ecosystems and the potential impacts on them associated with development schemes must integrate several disciplines and different research approaches into a comprehensive program. The advantages of an integrated or holistic approach are many. For example,

– more information is obtained per unit effort;

– important relationships that are lost when research is fragmented are easily revealed;

– research is done at the same level of biotic organization as the human impacts on the ecosystems;

– communication among specialists from different disciplines is enhanced as are the contributions of the disciplines towards problem solving; and

–information gaps are less likely to develop.

To assure the success of an integrated research program, it is necessary to organize projects around a central question or model of the situation under study. Figure 1 is a simplified model of any ecosystem in the Paraná River Basin. It includes a water budget, material budgets, and oxygen dynamics of the system. Lines represent flows of materials, arrows the direction of flow, circles are the external driving forces, and storages in biotic and abiotic compartments are represented by various symbols. This model does not provide information about the details of ecosystem structure and function but it clearly shows the following important characteristics:

– it separates external factor or driving forces from internal processes and storages;

– it identifies the main interactions among external factors, and the biotic and abiotic components of the ecosystem;

– it illustrates the open nature of the material and energy budgets of the ecosystem; and

– it identifies the breadth of measurements that need to be made for assuring basic understanding of the ecosystem.

This model applies to any size ecosystem in the basin from a small river section to the large Paraná River Basin taken as a single ecosystem. We use this model as a research planning tool and to illustrate how the different disciplines may interact to resolve a common problem. For example, hydrologists provide the water budget and chemists and ecologists combine to provide nutrient and material flow information, plant ecologists measure the storage and flux of organic matter within and through the ecosystem, and zoologists describe the food chains. All these measures are routinely taken as part of most research projects.

The collection of data should be coordinated by focusing measurements on the same ecosystem types, reporting results in comparable units with time and area dimensions, maintaining research progress at a pace suitable for all disciplines, and above all, making sure that all disciplines understand the central questions and can express their results in the same scientific language.

All research activities are valuable to science. One cannot categorically say that one research project is more important than another. Yet, in a program such as the proposed for the Midle Paraná, it is imperative that each research project responds to project needs and priorities and that each has a direct contribution to a common goal. This means that research projects will be assigned priorities without implying that a project with a lower priority is of less scientific value than one with a higher priority. Time and monetary constraints simply force planners to set priorities according to the need to answer questions of importance to the research goal.

Common problems in any research plan that require special attention are:

– different disciplines have different views of precision which makes research coordination difficult;

– results are expressed in forms that are not usable to other disciplines;

– common language of expression is hard to obtain; and

– problems of scale develop when results are extrapolated from one scale of biotic organization to another, e.g., from the laboratory to the field or from a population study to an ecosystem.

Constant communication and good will are the best palliatives to these problems. However, researchers should keep in mind that ecological work in large ecosystems such as the Middle Paraná can never be as precise as with individuals or populations. Furthermore, it is very dangerous to extrapolate results from laboratory conditions to large scale ecosystems. Experiments should be designed for the scale of biotic organization closest to the one at which the problem under consideration occurs.

PROBLEM OF SCALE

At what level of biological organization should studies be conducted? Should efforts be centered at a species or at an ecosystem level? If the ecosystem level is selected, how big should the unit of study be? These are critical questions in the Middle Paraná River because of the large size of the basin and the finite resources available with which to study it. At best, one must compromise. However, in any stage of project development, it is possible to develop a plan of study that covers all possible levels of biotic organization in the basin.

Ecosystems of the landscape can be classified hierarchically depending upon their size and the perspective of the observer doing the classification. In Fig. 2 the ecosystems of the Paraná River Basin are classified according to hydrological units as seen by an observer in a space station. Seven units are identified that begin at the rain-fed headwaters and terminate at the downstream estuaries. Arrows illustrate direction of flow for water and materials and each ecosystem unit represents a unit of structure and function that can be studied and manipulated as an ecological entity.

The construction activities in the Middle Paraná River affect ecosystems below and are affected by ecosystems above the site of construction. In order to evaluate environmental impacts of those activities, it is necessary to understand processes at this scale of biotic organization. Interactions between large landscape units are more important than interactions within each one. The ultimate goal of the proposed program should be to understand processes at this scale of organization.

We offer Fig. 3 as an example of the various levels of organization within one of the large scale units (the Paraná River Basin) that requires attention in those instances when research questions address problems of smaller magnitude. The diagram is also

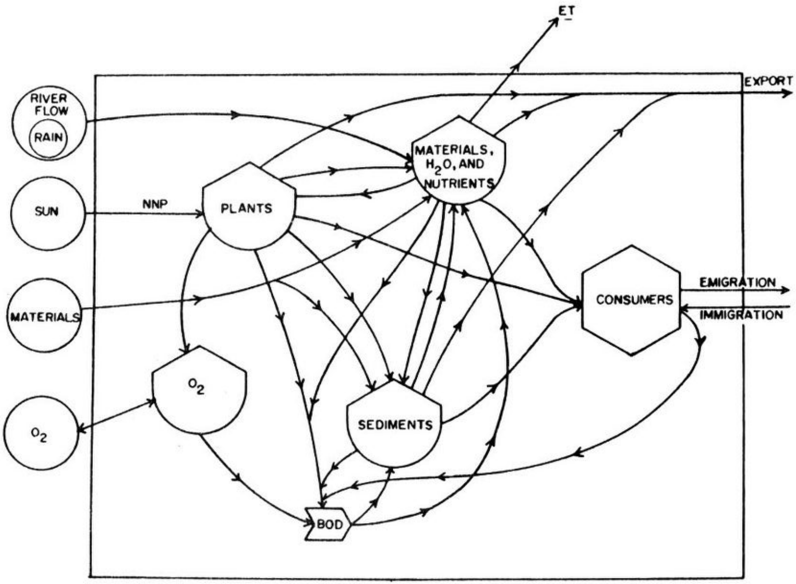

Fig. 1. A simplified model of the Middle Paraná ecosystem. This model emphasizes the water budget, material budgets, and oxygen dynamics within the ecosystem boundaries delineated by the box. Circles are the external driving forces and symbols within the box are storages of abiotic and biotic components of the ecosystem. Lines represent interchanges of storages in the direction of the arrows and also represent movements across ecosystem boundaries. See text for further explanation.

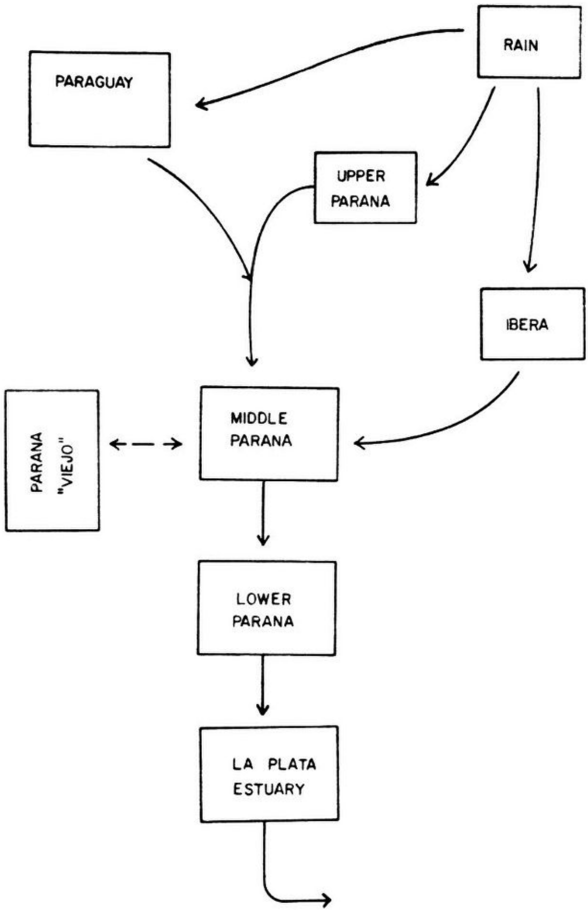

Fig. 2. Major hydrologic units of the Paraná Basin watershed and their relationship with each other. Each watershed unit conveys important characteristics to the one below it. To understand ecological functioning at this level, it is essential that the transfers of materials which occur in the region of the arrows be known.

a hierarchical organization of ecosystems, beginning at top with the largest unit and progressing down toward the smaller units of study. Intermediate aggregations of ecosystems are shown between the two extremes. Because of the great magnitude of the Middle Paraná project, it is imperative that the largest unit of study be understood. Studies at levels below individual ecosystems (the bottom of the diagram) should not be undertaken unless they are designed to answer large scale questions. For example, studies of migratory fish species are justifiable because these populations transcend ecosystem boundaries. Understanding their ecology is essential for understanding how the ecosystems of the basin are connected biologically.

The goal is to understand the Middle Paraná as a single ecosystem. Development of vegetation, soil, and other large scale maps is a tool that is useful for understanding the project as a single entity. In these instances where different disciplines are working at different scales and in different places in the project without a plan for integration, we recommend the following procedure:

– the ecosystems of the project area must be classified and mapped according to their functional and/or physiognomic characteristics;

– the area covered by each major type must be determined;

– comparative research should be conducted on each type to ensure that important ecosystems do not go unstudied; and

– as knowledge on the project area accumulates, measurements of larger ecosystem assemblages and processes should begin. For example, we propose that a monitoring network be established as a step in this direction.

CRITICAL RESEARCH QUESTIONS

The Middle Paraná River and its floodplain represent a system of inflows, outflows and storages of water and organic and inorganic materials (Fig. 1). One of the basic questions that needs to be addressed is how these flows and storages will change from present conditions once the dams are in place. The most important consideration, therefore, is to have equivalent data before and after the dam is in operation and during its construction.

To develop recommendations for an integrated research program in the Middle Paraná, we used the model inf Fig. 1 to identify the components of the research program that need attention. These are questions that pertain to hydrology, material storages and fluxes, consumers, impacts elsewhere in the system, and mitigation. Below, we treat each of these subjects by emphasising the main questions that pertain to the subject and need to be addressed, and possible approaches to their resolution. By addressing each subject from the point of view of research questions we hope to demonstrate the use of conceptual models to generate research questions and the value of questions to unify research efforts.

Hydrology

Because wetlands are driven by hydrological fluxes, hydrologic information is critical for understanding wetland ecosystem structure and function. Additionally, hydrological energy is responsible for transporting organic and inorganic materials in wetland systems and information on water flows is essential for the formulation of material budgets. Any change in hydrological characteristics results in fundamental

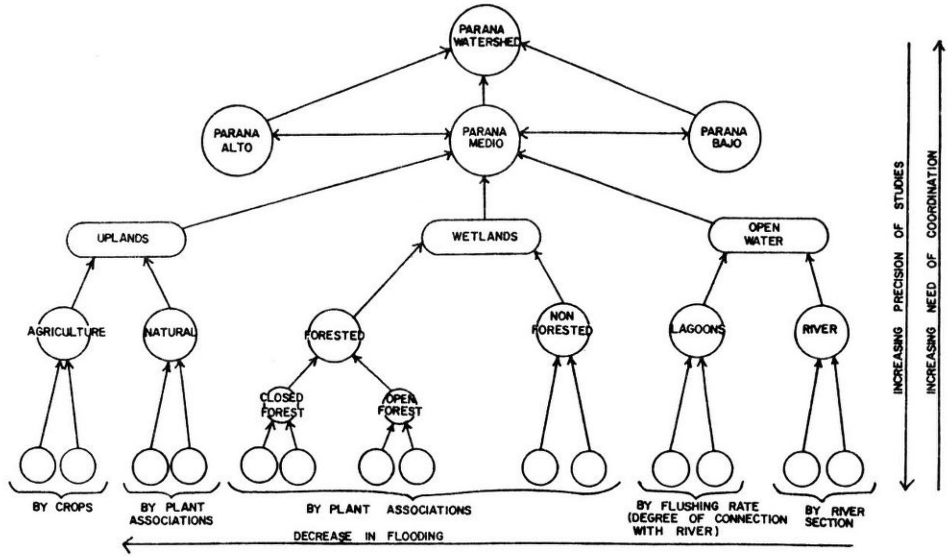

Fig. 3. Hierarchical classification of ecosystems within the Paraná Basin to the level of biotic communities. Each level requires an organized approach such as a conceptual model or set of principles for effective research. Investigators should be able to identify the level at which they are working and how their results will contribute to the understanding of the higher levels of the ecosystem organization. The levels are organized in a matrix composed of flooding frequency, precision of studies, and need for coordination.

changes in the structure, composition, and function of natural ecosystems as well as changes in the transport of materials throughout the basin. Our review of the hydrological models for the Middle Paraná established that the information being produced is adequate for the kinds of analyses ecologists need to perform in the basin. The research questions and recommendations that follow pertain to the ecological use of hydrological information rather than to the more technical hydrological considerations that are outside our expertise.

Results of the hydrological model suggest that during high flows in the Middle Paraná (about 30% of the year) the proposed dam will have no effect on water flow below the dam, but that during periods of lower flow (70% of the year) there will be some modification of the flow. Extreme modification of the flow will occur during 10% of the year at very low flows during the dry season. The modification of the flow regime results from the daily requirement of electricity production. Therefore, modification in the flow is exhibited as a diurnal oscillation in flow and depth (stage), with amplitude varying both with time of year (greatest amplitude during 10% of the year) and distance from dam (greatest effect in areas closest to dam with no effect at distances beyond about 100 km below the dam). Because of the potential impacts of flow modification on downstream ecosystems, the following research questions must be addressed:

– What ecosystem types and how much area will be affected by flow modification?

– What structural and functional characteristics will be affected in the different ecosystem types? (Refer to Fig. 1 and next section for guide).

– What effect does the duration of the extreme modification (i.e., short periods versus longer periods of time) have on ecosystem processes and species composition in the different ecosystem types?

We suggest that a field experimental approach is the best method to answer these questions because the answers are needed before the dam is put into operation in order to anticipate the consequences of flow modification. An example of an experimental approach is to select several major ecosystem types (e.g., lagoons of different sizes) and manipulate their inputs of water according to the predicted scheme resulting from the hydrologic model. Using Fig. 1 as a guide, determine which ecosystem processes and components are sensitive to the change in water flow. If manipulation of flows is impossible, the next best approach is a comparative study of natural lagoons that vary hydrologically and that most closely mimic those predicted from the hydrological model.

As part of the construction of the dam, some channelization in one of the streams (Rio Saladillo) will take place to facilitate the drainage of excess water above the reservoir during periods of high flow to prevent flooding of lands used for agriculture. For the wet season this may not create a problem. However, in the dry season it could lead to excessive drainage and increased salinity. For these reasons the impact of water regulation activities on soil salinities and the length of the hydroperiod must be investigated.

We suggest two methods of approach. One is to quantitatively describe the system at present, particularly its response (e.g. changes in soil salinity) to extreme water flow conditions, and to use this information to build a model of the system which predicts the response of the system to the altered hydrologic regimes. The second approach is to experimentally manipulate the water flow regime of part of the system and to measure the response of physical and biological characteristics to these changes.

Because the main driving force of wetland ecosystems is the water regime, all vegetation studies must include measurements of the depth and duration of flooding, depth of the water table, and the flow rate of water. When information for the hydrology model was collected, 42 transects across the Middle Paraná were surveyed. Information on flow, depth, and area of flooding is available for all of these transects. Therefore, to accomplish the above task and to increase efficiency of operations vegetation studies must be located in areas where detailed information on the hydrology is available.

Material Storages and Fluxes

Flows and storages of "materials" fall into three broad categories: (1) organic carbon which can be categorized as dissolved (DOC), fine particulate (FPOC), and coarse particulate (CPOC), fractions, (2) suspended sediments which are represented by sand, silt, and clay, and (3) dissolved ions and other elements.

Organic Carbon

The flows and storages of organic carbon are expected to change with operation of the dams and establishment of the reservoirs in the Middle Paraná. In addition to changes in these quantities, differences can be expected in the quality of organic carbon. In simplistic terms, the ecosystem will change from one in which wetlands produce large quantities of vascular plant biomass during the seasons of channel—confined flow to one which is less seasonally diverse and is driven by more continuous imports from upstream and *in situ* production by phytoplankton.

The following is a list of important questions that require parallel studies before and after dam construction to evaluate the significance of organic carbon flows and storages to both the metabolism of the Middle Paraná and La Plata ecosystems and changes in food webs (structure of consumer communities) that may result from the project. This list will be followed by some general suggestions on techniques and ways in which other studies might be amplified or coordinated to ensure greater relevance of the results to expected ecosystem alterations.

Flows of organic carbon. — Critical research questions are:

— What is the annual supply of organic carbon to the Middle Paraná from the two principal sources: (1) imports of DOC from the Paraguay and Upper Paraná Rivers at Corrientes and (2) the primary production of organic carbon by plants within the floodplain including aquatic and wetland components?

— What are the magnitudes of these sources of organic carbon and how can seasonal pulses be best characterized?

— How does the export of organic carbon from the Chapeton area compare with that imported to the Middle Paraná at Corrientes?

— Are there significant differences in the quality of organic carbon (particle size, chlorophyll content, carbon/nitrogen ratio) between inflows and outflows?

— To what extent do these exports represent supplies to La Plata estuary?

— In what manner will these flows be changed with establishment of the reservoir and what is the best sampling approach to detect these changes?

Comprehensive studies or primary productivity are important because they provide information about the speed of organic production by different ecosystems and those undergoing alteration. This information is useful for determining the amount and quality of food available for consumers through grazing and detritus food webs. The current state of knowledge suggests that primary productivity in the river channel is low (less than 800 mg C m^{-2} day^{-1}), and that it is higher in lagoons isolated from channel flow (about 2000 mg C m^{-2} day^{-1}), than in lagoons connected to the river (about 1300 mg C m^{-2} day^{-1}). Comparable studies in marshes and forested wetlands are not available although there are some estimates of productivity for several aquatic plant species such as *Eichhornia.* We suggest that:

– More emphasis should be given to primary productivity measurements in a variety of ecosystems, perhaps in proportion to the area they cover in the basin.

– These studies should be conducted along the transects established for vegetation descriptions.

– Standard methods of primary production determination (published by the International Biological Program) should be used in these studies.

– Sampling should include all of the ecosystem producers, not only the dominant species.

– Primary productivity studies should be closely coupled to other studies of organic carbon flow (e.g., decomposition and export) and storage to assure that a more comprehensive understanding of the carbon dynamics is achieved.

It appears that the combination of laboratory and field studies on decomposition represent a logical approach for contributing necessary data for an oxygen demand model for filling the reservoir. However there are several suggestions that may be considered, and if they are perceived as valid, should be implemented.

– Field studies using litter bags should be also done in those environments where problems with anaerobic conditions are most likely to develop. The combination of negligible flow, deep water, abundant plant biomass, low light penetration, and thermal stratification represents the most favorable conditions for anaerobiosis. If resources are available, the field studies should be coordinated with those on primary productivity.

– A compromise must be reached between precision of measurement and the number of experimental treatments in the design of both field and laboratory studies. We suggest that two significant figures in most of the measurements are sufficient for various steps of analysis. By reducing the precision of analysis somewhat, more time may be available for expanding the experimental design to include more environmental variables that may control decomposition rates.

– Regularly scheduled meetings should be held among members of the decomposition group, the modelers for oxygen demand, and the group measuring plant biomass. Data should be applied to the model as the data are collected, not at the end of the projects. Some system of interchange of data and reports should be organized between the three groups.

– In order to expand the variables treated in the decomposition study, more resources in terms of manpower, equipment and support services should be made available.

Storages of organic carbon – The work on plant biomass in transects of the Middle Paraná provides essential information. As mentioned previously, we strongly recommend that these transects be coordinated with those used in the hydrology model. Another potentially large storage of organic matter exists in the soils and sediments.

We suggest that the following information be acquired:

– A soil and sediment sampling program is needed along the vegetation transects and from the river channels and lagoons that lack vegetation. Bulk density of sediments and soil from these samples are necessary for calculation of organic carbon on a unit area basis.

– The investigators conducting the vegetation analysis should discuss their classification approach with those involved in studies on consumers (birds and fishes).

Sediments

This phase of the research program is being studied by the hydrologists who have incorporated the dynamics of suspended sediments into their hydrologic models. Because the concentration of suspended sediments (clay, silt and sand) remains fairly constant (as does water flow) with distance along the Middle Paraná, it is assumed that rates of deposition are balanced by rates of erosion, and no net deposition occurs. However, deposition probably occurs in the floodplain which is balanced by erosion in the channel. Without sediment accumulation in wetland areas of the floodplain, sediment concentrations may increase along the length of the river. We, therefore, suggest that studies be initiated in the floodplain to measure rates of deposition in relation to the magnitude of flooding. This can be accomplished by placing permanent stakes in the ground at given intervals along transects, such as those already surveyed by the hydrologists and those established for vegetation biomass studies. The amount of material (depth changes) deposited or eroded is determined by annual measurements of the length of the stakes above ground surface.

Results of simulations of the hydrologic model predict that after the dam is in operation, fine sediment concentrations will decrease significantly below the dam and that essentially all of the large particulate sediments will be retained in the reservoir. However, the models suggest that erosion of the channel along a 100 km length of river downstream from the dam will increase concentrations of larger particle sizes to those encountered above the dam. Because these modifications in sediment concentrations have potential impacts on ecosystems downstream from the dam, we suggest studies be initiated to answer the following questions:

– How does the sediment from the Middle Paraná function in La Plata estuary?

– With a reduction in sediment supply to the estuary, what changes may be expected in the composition of the bottom, transparency of the water column, and the response of the plant and animal communities?

– What effect will increased erosion in the area immediately downstream from the dam have on drainage patterns of the floodplain system?

– To what extent does the Paraná delta in La Plata estuary depend on sediment supplies to maintain its size and elevation.

To address the first two questions we suggest that research be initiated on the circulation of sediments in the estuary, particularly in the turbidity maximum zone, and that the history of sedimentation rates be examined from sediment cores using isotopic markers (e.g., ^{14}C, ^{210}Pb, ^{137}Cs).

Other Materials

The flow of other materials can be viewed from two perspectives: (1) a strict ecological materials budget where the floodplain and river ecosystems cause changes in composition and concentrations of elements as detected from differences in inflows and outflows, and (2) a public health approach where water quality data are collected to detect pollutants such as disease–causing microorganisms, toxic chemicals, and excessive nutrient concentrations which may cause "unfavorable" plant production. We address both of these areas with general suggestions on the intensity and frequency of sampling and analysis.

Ecological materials budget – Our suggestions are:

– Coordinate sampling with hydrological measurements (as was suggested for organic carbon and sediments) so the flow rate of elements can be calculated and predictive relationships can be developed between flow and concentration. Ensure that, at a minimum, water samples be collected from all sampling stations currently used by the hydrologists, although not necessarily at the same frequency of sampling. However, sampling frequency should be proportional to rates of discharge.

– Do not measure all parameters with the same precision and frequency. For example, biological nutrients such as nitrate, ammonium and orthophosphate may be expected to change depending on demand by plant growth and exchange with sediments. However, more conservative elements such as calcium, magnesium, sodium and chloride will be less sensitive to these exchanges and can be sampled with less frequency. Conductivity data may now exist with which these major anions can be correlated.

– Investigators should standardize their analytical methods by using methods approved by such groups as the International Biological Program, U.S. Environmental Protection Agency, or the American Public Health Association. This may require a "workshop" to reach a consensus among investigators followed by reciprocal exchange of samples and standards among laboratories to ensure that data are comparable. Another approach is to centralize the analyses in one laboratory and organize a network of "field monitors" who collect and ship samples to one place.

– Synthesize information that now exists on water chemistry using a predictive (correlation among parameters) rather than a descriptive approach.

Water quality – We suggest the following:

– Data on water quality that may have public health implications should be first collected from those areas near present and future sources of contamination and not necessarily at those places used for measuring flows of ecological significance. Sediments should be examined for potential accumulation of toxic metals.

– Hydrologists often refine their one-dimensional models to produce two dimensional ones that will provide more information on circulation patterns within the reservoirs. Ecologists should use the results of these models to identify possible areas in the reservoirs that will have little water exchange. These are the places where phytoplankton production and accumulation of floating vascular plants will likely be greatest. Information from a two dimensional model will also be useful for planning future work in the reservoirs on ecological processes and public health concerns.

Consumer Communities

In this section we will attempt to identify some of the more obvious questions that need to be answered for predicting changes that will occur in vertebrate animal communities when the Middle Paraná is flooded and dams are in operation. Some of the effects on species are almost too obvious to mention. For example, many of the birds and mammals that depend on the seasonal availability of a wetland habitat will simply cease to exist or will be restricted to small, suboptimal habitats. Others, such as the fish communities, will undergo large changes in species composition because of changes that occur in their food supply, reproductive needs, and other habitat features to which their behavior and survival are dependent, in spite of the engineering plans to assist migrations through the dams. These changes will be felt far beyond the boundaries of the Middle Paraná and may even occur throughout the entire drainage basin.

Fish Communities

We suggest that information be gathered to answer the following questions:

– Some fish of commercial importance are migratory and the needs of various parts of their life cycle must be met in different habitats. What proportion of the fish community consists of anadromous, catadromous or resident species?

– For the migratory species, is their movement related to reproductive needs, food requirements, or other habitat requirements?. What is the extent of their migratory routes upstream or downstream from the Middle Paraná?

– In what habitats (river channel, lagoons, tributaries, etc.) do migratory and resident species spend most of their time? How many species will lose habitat critical to their survival when the Middle Paraná is flooded?

– To what extent will changes in materials supply (sediments, organic carbon, and fresh water) to the La Plata estuary have an effect on fisheries and food chains in the estuarine ecosystem?

– To what extent will changes in commercially important species affect the social and economic structure of human populations dependent on fisheries?. Will new fisheries resulting from the reservoir provide significant commercial opportunities? Will the fisheries require controls and regulations?

Bird Communities

The following questions must be considered:

– Based on the known requirements of major species groups (guilds), is it possible to predict changes in species composition of the avifauna when the reservoir is in operation?

– What is the expected decline or increase in population density of various species upon operation of the dam?

– Is the Middle Paraná an important flyway and staging area for migratory waterfowl and other bird species?. What areas of the continent will be most affected by population reduction?

Other Consumers

Research in this area must consider the following:

– Are there data on population densities for any other species of animals that will be useful in predicting gains or losses that occur as a result of the reservoir?

– Are there any species in the endangered or threatened category on a world–wide basis?

– Is there a dependence of upland wildlife on the seasonal presence of wetlands in the Middle Paraná?

– To what extent will the establishment of natural reserves replace the wildlife values of the Middle Paraná? Will these reserves be maintained in their natural condition, or will they be subjected to alteration by human activities?

Impacts Outside Project Area

Ecological impacts outside the project area can be separated into primary and secondary effects. A systematic evaluation of these impacts must be made so that measures can be taken to seek alternative solutions to minimize negative effects.

– We suggest, as a first step, the development of synthesis papers because they are helpful in formulating conceptual models of the effects of the reservoir on areas outside of the immediate area.

– Once the synthesis work has been done (although it should be a continuous process as more data are available), we suggest that interdisciplinary teams systematically evaluate these outside impacts. These teams should include engineers involved in the structural design of the dam, hydrologists that have developed the flow models, ecologists that were involved in information synthesis, government officials aware of national issues, locally elected government officials, and representatives of civic groups from the population of the affected regions. The evaluation of impacts both within and outside the immediate area of the Middle Paraná will require a mandate and agreement from various project directors.

One of the most straightforward approaches toward impact assessment is to create a matrix composed of (1) existing ecological, societal and structural attributes of the outside area affected, (2) the nature of the activities of the project. Where the activities of the project interact with existing attributes, the evaluation team would seek possible alternatives or mitigation solutions that would minimize impacts. Many books are available that discuss approaches to impact assessment. We suggest that the processes of impact assessment be formalized for areas outside of the immediate area of the Middle Paraná.

One of the advantages of studying the functioning of ecosystems prior to the onset of construction and operation activities is that the ecological understanding gained can be used to mitigate damages to the ecosystem. Two aspects of mitigation involve (1) the setting aside of natural reserves to buffer the impacts of the reservoir or to simply maintain the natural balance of the region and (2) the anticipation of potential impacts of construction and operation activities so that preventive steps may be taken before damage occurs.

We have concerns about these two types of mitigation activities in the Middle Paraná project. It is not clear whether the operation of the reservoir will change hydrologic conditions in wetlands downstream from the dam and in the Old Paraná River valley. These alterations could create considerable ecological change and it is necessary that some evaluation be made so that mitigation alternatives can be explored.

Therefore, we suggest the following:

– Steps should be taken to begin descriptive and functional studies of ecosystems in the Old Paraná River valley and in the wetlands located below the proposed dam.

– Knowledge is needed on the responses of wetlands in the dry Saladillo River region as well as wet climates (below the dam) to changes in hydrology.

– Legal mechanisms to assure long–term protection of the proposed reserve areas must be found and used. The Ibera should be declared a Biosphere Reserve under the Man and the Biosphere Program.

Figure 4 is a generalized study plan with suggested time intervals. The first 1 or 2 years should consist of developing conceptual models of gains, losses, and storages of materials based on existing data, in addition to the continuation of most of the data collection that is currently underway. The purpose of this exercise is to determine what

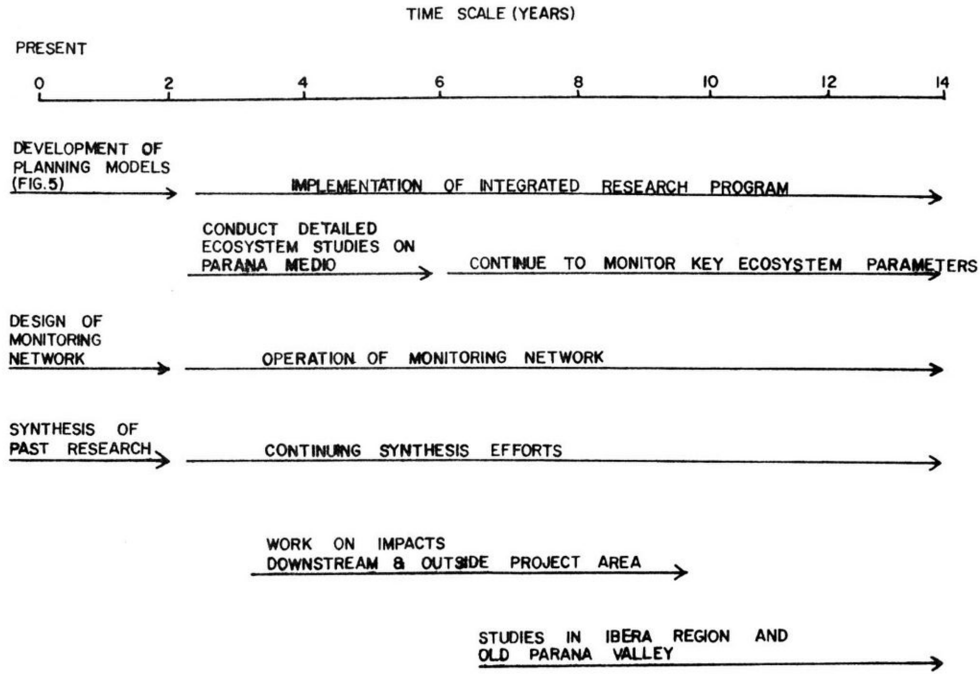

Fig. 4. A hypothetical schedule of work for ecological activities in the Middle Paraná region. Implementation of this schedule would require a substantial increase in project support.

should be measured and the frequency of measurements to produce the most efficient collection of data. This may allow several years to develop a data base before the first dam is closed and so that the resulting impacts can be monitored.

ORGANIZATION OF MANPOWER

In large and complex projects it is necessary to provide mechanisms to coordinate individual research projects, provide quality control, sharpen the focus of studies, provide research support services, maximize the flow of information, and assure synthesis of results. We make two suggestions to accomplish these goals.

– A seminar series (monthly seminars among participants and an annual symposium open to all the scientific community) and a mechanism for the circulation of all research documents among project participants should be implemented at once. This recommendation would increase the efficiency of researchers by making them aware (through seminars and documents) of activities and progress in other areas of investigation. Maximum interaction among researchers always leads to better integration, improved experimental designs, and faster solution of problems. The submission of multi-investigator proposals should be encouraged.

– A project organizational scheme (Figure 5) should be followed to facilitate planning, execution, synthesis, promulgation, and implementation of research results. The proposed scheme consists of the following:

a) a research planning team composed of all research project leaders and field managers;

b) a decision–making body that allocates funding and provides clear mandates to Argentinian institutions to proceed with approved research plans;

c) a pool of scientists from various Argentinian institutions working on different phases of an integrated research plan designed to resolve important questions associated with the impact of water works in the Middle Paraná;

d) outside peer reviewers that advise researchers and decision makers so that the scientific quality of the work is assured;

e) a group of ecosystem oriented scientists whose job is to integrate individual studies into comprehensive schemes useful to field managers. Through the use of computers, statistical analysis, and modern tools of data display and manipulation, patterns and principles of ecosystem function should be uncovered. The products of this working group are state–of–knowledge documents, maps, simulated models, charts and diagrams, all of which should facilitate the interpretation of data and clarify field observations; and

f) a Research Support Services staff that provides the essential needs of scientists working in large scale ecosystems. These include statistical services, automatic data processing, library services, logistic support, drafting services, etc.

– A document bank should be organized to maintain a control on information flow and assure research quality through the availability of up–to–date information. This can alleviate such problems as scattered information and the fact that some investigators work on the same ecosystem processes in different parts of the river, but are unaware of each other's results or are unknowingly using different methods.

– Fellowships for advanced training in ecosystem analysis should be given to promising students with backgrounds in ecology, chemistry, mathematics, and physics.

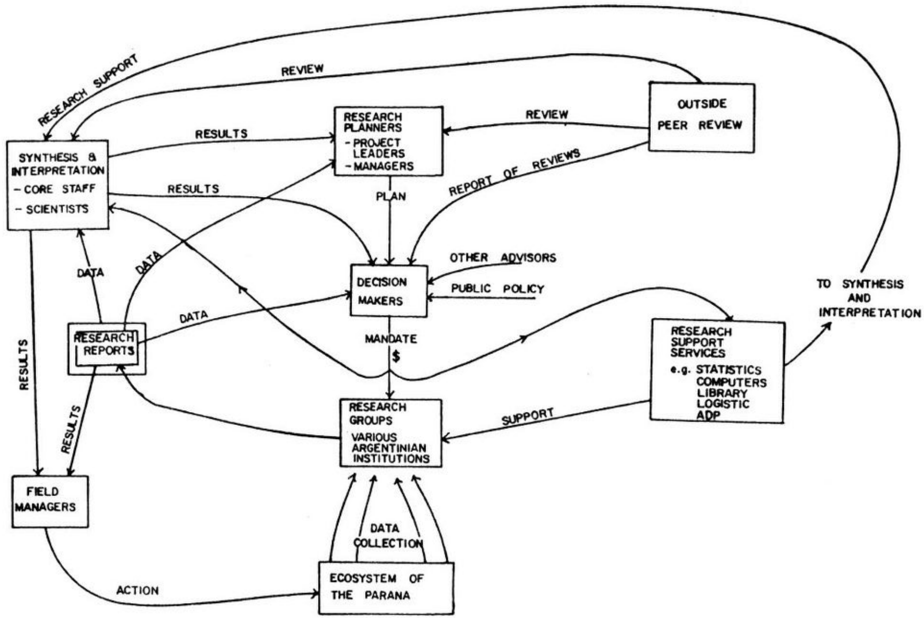

Fig. 5. Scheme of project organization to facilitate planning, execution, promulgation, and transfer of research results to user groups. See text for explanation.

The suggestions given above should help unify the research effort in the Middle Paraná project, provide a sense of unity among scientists, increase communication, and provide a mechanism for organizing the collection and interpretation of data.

CONCLUSIONS

Large–scale development projects, such as the impoundment of the Middle Paraná River for power production, result in alterations at a scale that is seldom dealt with ecologically. One of the greatest challenges to researchers is to plan and execute the collection and synthesis of information on ecosystem processes on a scale similar to that of the impact. Conceptual models of ecosystem structure and function are a starting point that helps to rally disciplines toward answering critical and central questions. Hierarchical schemes of ecosystem components can be used for researchers working at one level in the hierarchy to test hypotheses at the next higher level of organization. Finally manpower must be organized so that the information generated through the research is made available to decision makers in a timely manner and in a form that clarifies ecological consequences of ecosystem manipulation.

The critical research questions that we proposed were made during a brief visit and without a full appreciation of the historical context in which information was developed. It is now apparent that the information necessary to address some of those questions is appearing in the peer-reviewed literature[2]. However, the Middle Paraná and other large scale projects will require further synthesis of information across disciplines in order to generate answers that will minimize risks of ecological damage and create opportunities for mitigation.

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