HYDROELECTRIC PROJECT IMPACTS ON STIKINE RIVER ECOSYSTEMS - AN OVERVIEW

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HYDROELECTRIC PROJECT IMPACTS ON STIKINE RIVER ECOSYSTEMS - AN OVERVIEW

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PREFACE

Major rivers and attendant estuarine systems on the Alaskan coast, though few in number, contain highly productive habitats that support important fish and wildlife resources. Fish and wildlife can be strongly affected by various development projects, including hydroelectric power generation.

The objective of this study was to develop a report which would aid managers in predicting and mitigating effects of hydroelectric development on ecosystems associated with the Stikine River. This report describes the structure and function of affected ecosystems (riverine, riparian, and estuarine), reviews general effects of hydroelectric development, and presents summarized information from ongoing Stikine River studies.

ACKNOWLEDGEMENTS

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INTRODUCTION

Hydroelectric Project Description

Hydroelectric development of the Stikine watershed received reconnaissance study in 1964 and 1965 by the British Columbia Department of Lands, Forests, and Water Resources. Subsequent investigations during the 1960s reduced 19 potential dam sites to eight. In 1972 formulation of province-wide hydroelectric development plans by the British Columbia Energy Board led to renewed efforts. Recent feasibility studies by British Columbia Hydro and Power Authority (B.C. Hydro), a quasi-governmental agency, commenced in 1977; these efforts have culminated in a plan to examine the possibility of five damsites - two on the Stikine River and three on its largest tributary, the Iskut River.

The Stikine dams as presently designed would be among the largest in North America, produce reservoirs over 95 km long, and add approximately 2800 megawatts of capacity to the existing system. Although projections of future energy needs are transitory and highly controversial, it is generally accepted that increased power would be initially utilized for mineral development in the area. Power in excess of these needs could be exported to other regions, including the United States, via power line networks.

After initial plans were formulated, B.C. Hydro informed state and federal natural resource agencies in Alaska of their activities, and requested the identification of potential concerns. A task force composed of resource agencies of both countries was formed to facilitate exchange of ideas and voluminous studies issued by investigators in Canada and the United States. During periodic meetings, results of ongoing studies and needs for additional information were discussed. Although the task force is still active, no mechanism has been developed that ensures United States' participation in decisionmaking at policy and planning levels.

The process of obtaining an Energy Project Certificate for hydroelectric development under the Canadian Utilities Commission Act is somewhat analagous to the application for a Federal Energy Regulatory Commission permit in the United States. B.C. Hydro status reports indicate adequate information will be generated by July 1984 to initiate application to the Ministry of Energy, Mines, and Petroleum Resources. However, B.C. Hydro has recently indicated it may delay license application by three or more years. Such a delay could allow a more complete understanding of the systems involved, and thus more accurate predictions of the consequences of development, if additional studies occur.

Affected Area

The 51,000 km^2 Stikine River basin, located in the northwest corner of British Columbia, lies immediately adjacent to southeastern Alaska (Figure 1). The Stikine originates in the Skeena Mountains, flows 565 km in a generally westerly and southerly direction, transects a chain of coastal mountains, passes 35 km through Alaskan territory, and terminates in a deltaic marsh complex near Wrangell, Alaska. The Stikine's largest tributary, the Iskut River, joins the system 11 km upstream of the British Columbia - Alaska border.

Geomorphology

The primal Stikine River may have developed 50 million years ago. The Stikine Plateau and the Coast Mountains, through which it flows, have been subject to uplift during the last 7 million years. The most recent ice age

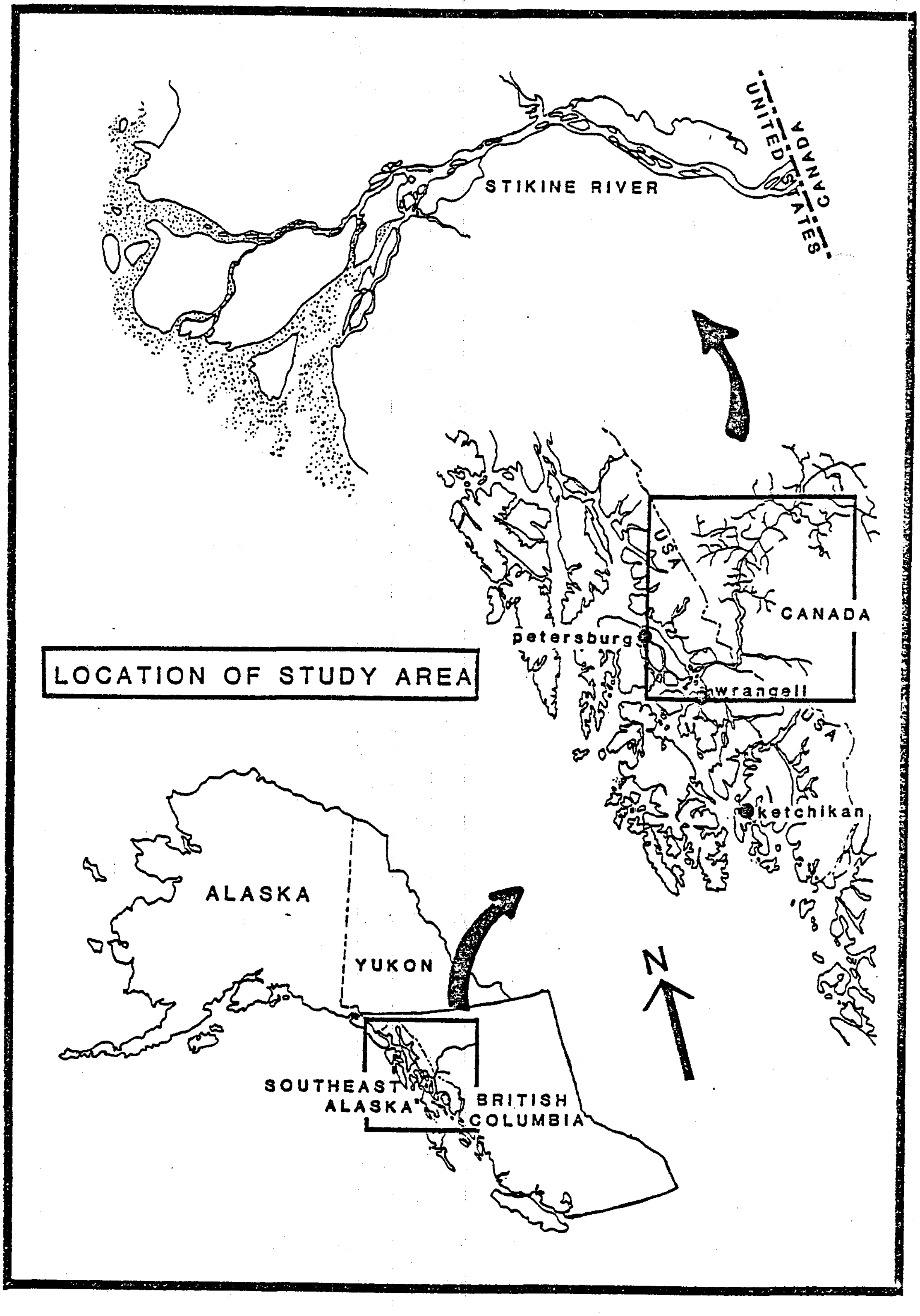


Figure 1. Location of Stikine River study area.

(10,000 to 15,000 years ago) blanketed the drainage basin, except for the tallest peaks, in ice and snow. As the glacial mass receded (a process still occurring), rounded valleys were formed and the region experienced isostatic rebound. Estimates of the rate of recent land emergence approach 0.3 cm per year (Dipert 1975; Hicks and Shofnos 1965; Twenhofel 1952).

The headwaters of the Stikine traverse the Stikine Plateau - a relatively dry, wide-open, gently-rolling upland containing many ice-scoured valleys. Approximately 290 km from its source, the river narrows into the Stikine Grand Canyon, which stretches for 97 km and forms a barrier to fish and human traffic. Near the middle of this boiling whitewater the slope is 7.6 m/km. Below the Grand Canyon the average slope approaches 1.5 m/km, and the river, fed by meltwater of numerous glaciers, eventually becomes the familiar, wide, muddy Stikine. The turbid waters pass through valleys of the Coast Mountain chain just prior to disemboguing in the Stikine estuary, located behind a series of mountainous barrier islands that form part of the Alexander Archipelago.

Climate

Two distinct zones, separated by Coast Mountain peaks approaching 1,500 m, comprise the Stikine basin. These Coast Mountains form a barrier to moist Pacific air approaching from the west and southwest; hence the narrow, maritime region is subject to precipitation frequently exceeding 250 cm per year. The wettest period is September through November. Mean monthly temperatures range from 1°C in January to 15°C in July. Climate on the landward side of the Coast Mountains is continental - characterized by long, cold winters, short, cool summers, and average annual precipitation of

50 cm, 50 percent of which falls as snow. Precipitation in this interior region is evenly distributed throughout the year. Mean monthly temperatures range from -18°C in January to 15°C in July.

Hydrology

A paucity of long-term gauged flows exists for the Stikine basin, but a general pattern of discharge can be described: low winter flows (December-March); spring/summer flooding rising to a crest (April-September); decreasing flows interrupted by periodic floods. Stikine discharge records are inadequate to produce flood frequency curves; extant data indicate monthly mean discharge ranges from nearly 4,000 m^3/sec in July and August to approximately 200 m^3/sec in January through March. This wide variation exists because three separate processes interact to determine the flow regime of the lower Stikine River: (1) snowmelt on the interior plateau, (2) glaciermelt in the Coast Mountains, and (3) rainfall on the Coast Mountains. The latter two rates tend to peak in late summer, resulting in high discharges of that season. Unusually high, short-lived discharge rates in October are attributable to major fall rainstorms.

Although plagued by a lack of data, estimates indicate the Stikine's annual suspended sediment load is 16.3 million metric tons. Composition of the material has also been estimated: sand, 40 percent; silt, 38 percent; clay, 22 percent (B.C. Hydro 1982; Beak Consultants 1982).

STRUCTURE AND FUNCTION OF AFFECTED ECOSYSTEMS

A tacit goal of every participant in the development of a hydoelectric project - whether sponsor, engineer, biologist, or bureaucrat - is to implement a program with the fewest problems, present and future. To accomplish this goal, the strategy a biologist typically employs is to predict impacts and suggest mitigation by combining two essential sets of information: (1) details of project construction and operation, and (2) knowledge of the dynamics of affected ecosystems.

To attain this goal, many approaches are available; Ward (1978) discusses the benefits of a system-level examination, even in those cases where interest is focused on selected species or portions of the ecosystems. Cummins (1974), in a stronger stance for studying structure and function of ecosystems, stated the emphasis on species units has been (and will continue to be) a major constraint in the understanding of ecological concepts. McIntire (1983) concurred and suggested emphasis be placed on processes of systems. In a review of stresses resulting from environmental alterations, Lugo (1978) argued that studies and analyses must ultimately be conducted at the ecosystem level. Advantages of a system-level focus are undeniably extensive; perhaps the most important is that it forces managers' attention toward relevant questions. Thus, after discerning/predicting that a change in a system component will occur, we are led to ask "Will this affect the maintenance of the entire ecosystem? Other systems? If so, to what degree?"

An ecosystem can be visualized as a series of components (e.g. species populations, organic matter, nutrients, physical processes) linked by food webs, nutrient flows and energy flows. Boundaries of a system are arbitrary, and are usually determined by the purpose of an investigation. Because connections between components in a system are complex, diagrams depicting conceptual models of ecosystems are frequently employed. To ensure increased uniformity, Odum (1971) proposed a shorthand for use in these conceptual models. A conceptual model can be a preliminary step in constructing empirical or simulation models. Frequently it represents the final stage of an undertaking, especially - as is the case in this project - when environmental data are sparse or lacking (Cooper 1969).

Neither a conceptual nor a simulation model has been published that would accurately represent the Stikine River - a large, turbid, relatively undisturbed, sub-arctic ecosystem driven by a combination of rainfall and melting glaciers. Indeed, many authors have lamented the lack of information concerning northern aquatic systems. This paucity is due to logistic difficulties of research in cold regions and lack of economic development pressure; the latter has historically been a strong motivation for research. An early document issued by B.C. Hydro (Beak 1981) indicated the ecosystem-conceptual-model approach to project evaluation would be followed; however, it was abandoned in subsequent reports. Even if no entity involved in this hydroelectric project develops a formalized conceptual model for the Stikine ecosystem, all participants should be encouraged to examine their contributions at this level.

Riverine

Given the lack of a pre-existing model and adequate site-specific data for conclusions, one prudent approach is to examine: (1) generalized conceptual models of riverine (lotic) systems and assume, in the absence of conflicting data, that major components and linkages are similar, and (2) data concerning systems that appear to be similar.

Authors have produced conceptual riverine ecosystem models at varying levels of complexity. A simple model is shown in Figure 2; one with more detailed components and interactions is shown in Figure 3. Regardless of the level of complexity, driving forces (forcing functions), major components, and energy flows depicted by noted authorities are in agreement. Reviews of Cummins (1974), Hynes (1970), Paul et al. (1983), Vannote et al. (1980), and Vannote (1981) are representative, and corroborate the following descriptions.

The overriding characteristic of lotic ecosystems is their continuous nature - constantly deriving material and energy from upstream, processing it, and passing it downstream. As the order of a stream/river increases, types, sources, and fates of organic materials that drive the biological system change. Four general categories of organics can be identified: primary producers, detritus, dissolved organics, and consumers. Partitioning these categories allows greater attention to details. For example, primary producers are typically subdivided into phytoplankton, benthic algae, and vascular plants. Detritus is composed of large/coarse particulate organic matter (LPOM/CPOM) and small/fine particulate organic matter (SPOM/FPOM). Interrelationships of these components are frequently the subject of research; Figure 4 illustrates a general model offered by Webster, Benfield and Cairns (1979). Animal consumers are commonly divided into shredders, grazers, scrapers, collectors, and predators. Dissolved organic matter (DOM) and nutrients are split into specific compounds or elements when necessary. Many of these components and some of their interrelationships are shown in Figure 5; additional discussion follows.

A fundamental concept of lotic-system ecology is that autotrophic processes are negligible in small-order streams (1-3); they can only become significant if and when stream velocity, turbidity, temperature, and other

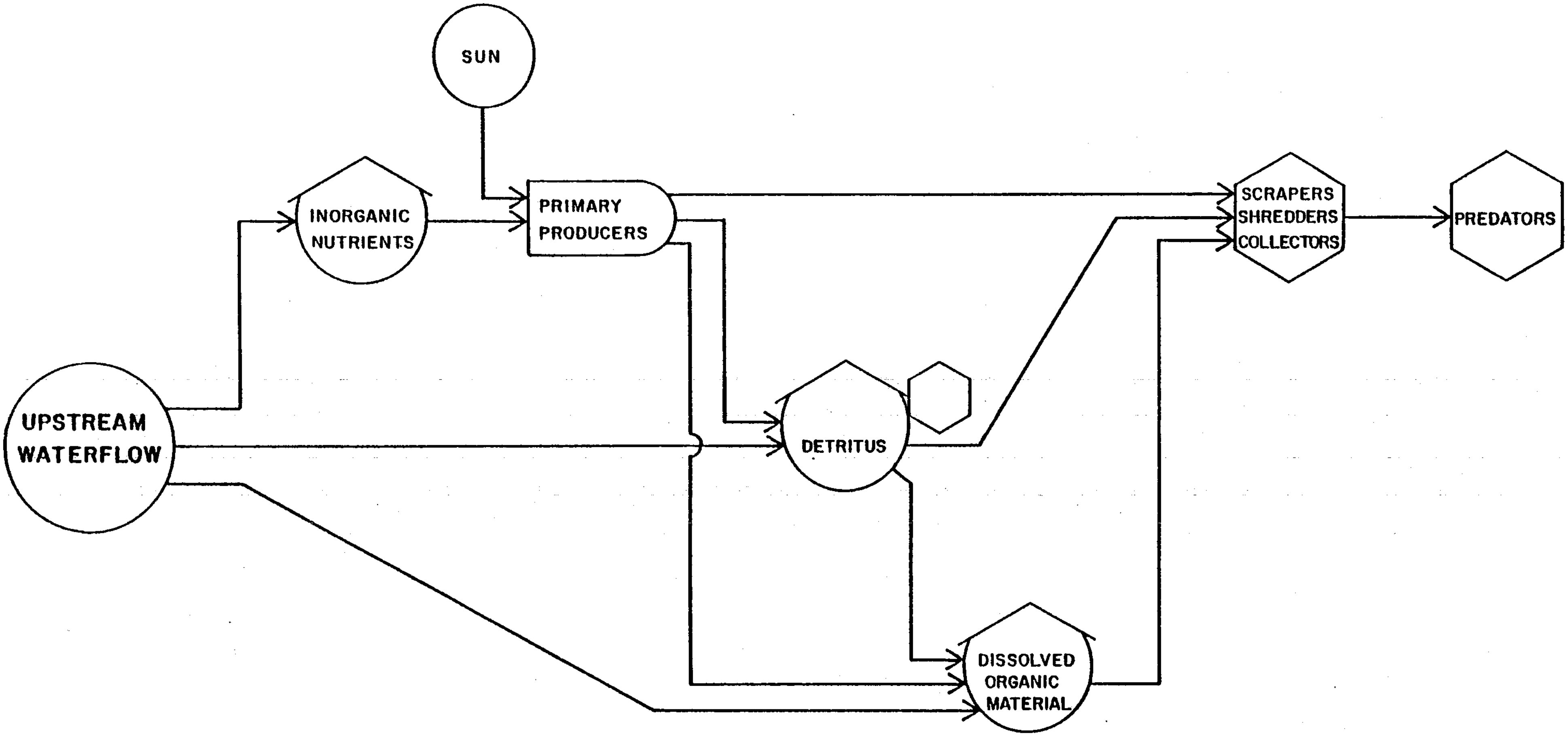


Figure 2. Major pathways of energy flow in a stream segment.

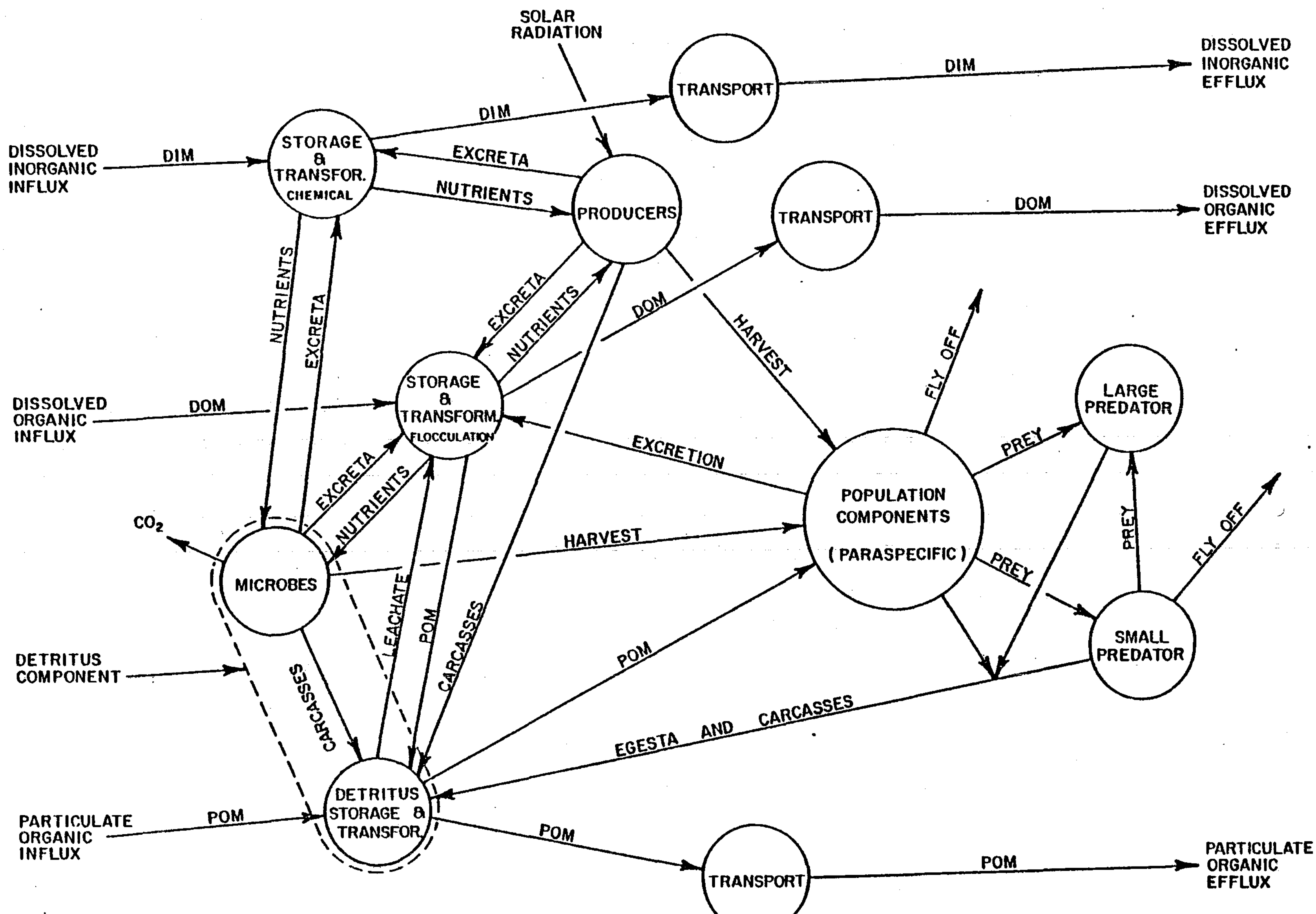


Figure 3. Conceptual model of a stream (modified from Boling et al. 1975).

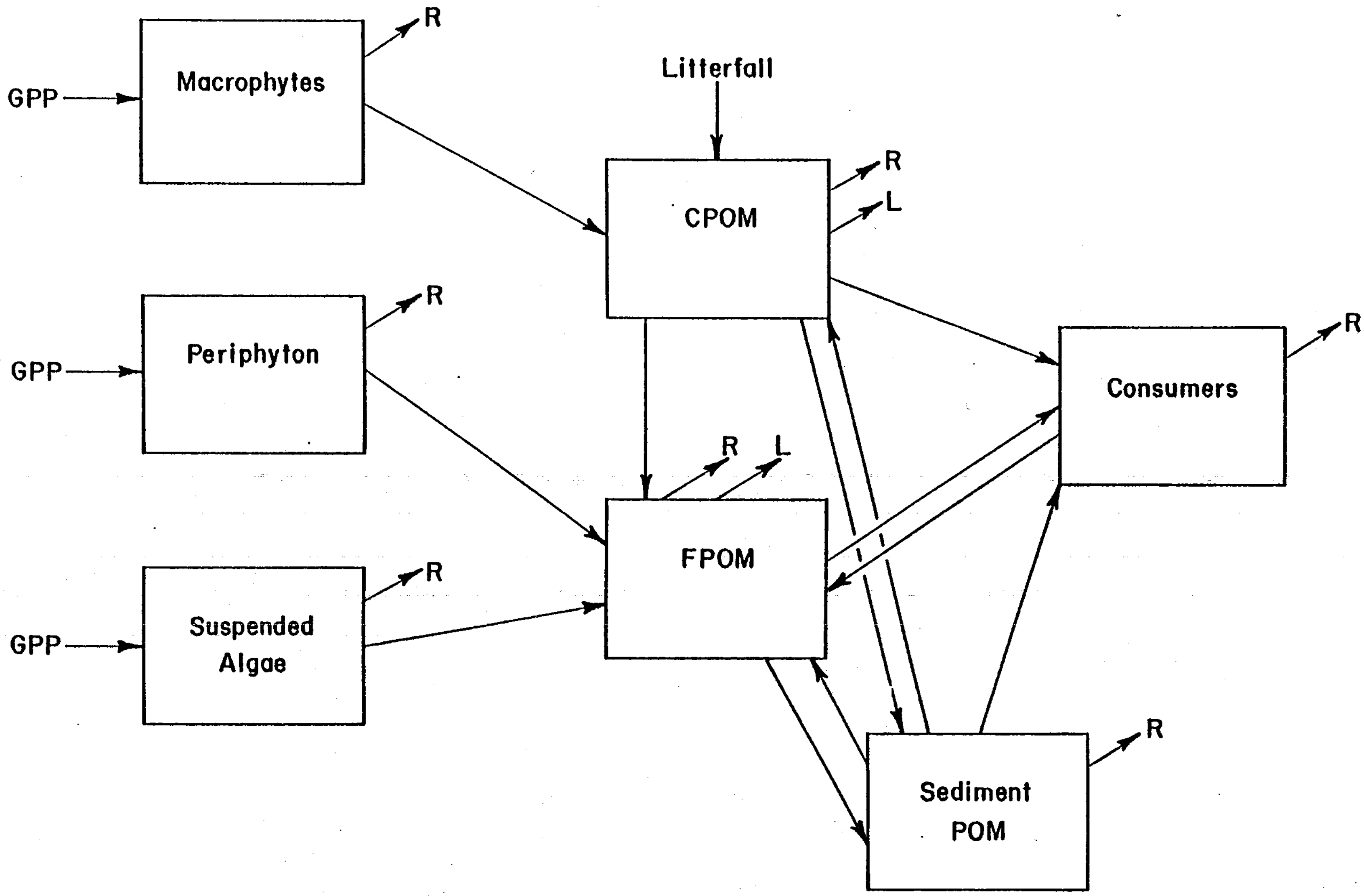


Figure 4. General particulate organic matter interactions in a stream ecosystem (modified from Webster et al. 1979). GPP = gross primary production; R = respiration; L = leaching; CPOM = coarse particulate organic matter; FPOM = fine particulate organic matter.

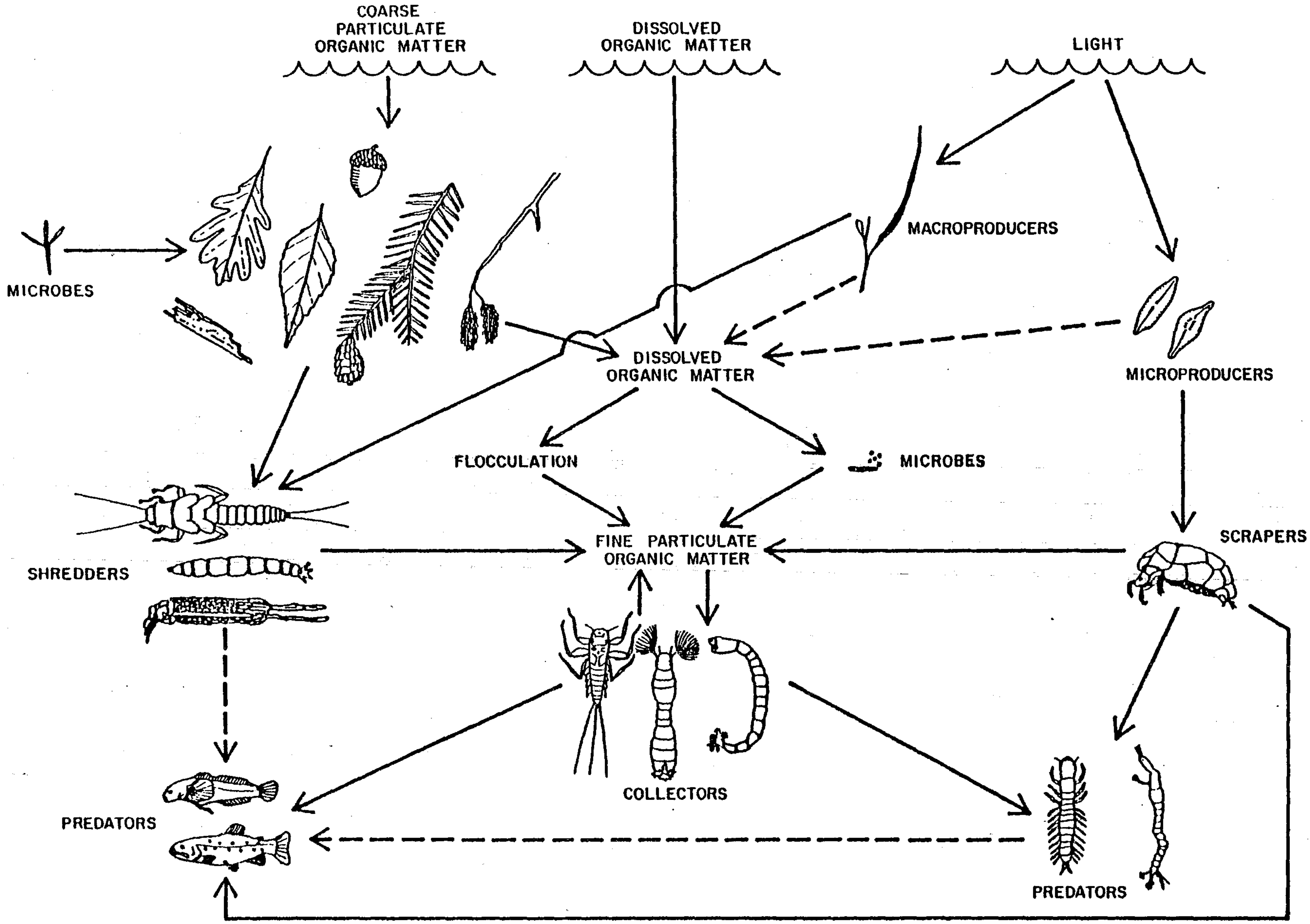


Figure 5. A model of organic matter processing in a stream (modified from Cummins 1974).

conditions allow (stream orders 4-6). Thus, a large riverine system is dependent on importation of organic and inorganic materials. Cummins (1979) offers a concise discussion and diagram of this feature (Figure 6).

Coarse particulate organic matter (> 1 mm diameter) enters the system in the form of leaves, needles, branches, bark, flowers, fruits, etc. Very large particulate organic matter, in the form of logs, may enter the system during flood events. The material is processed by different components as it travels downstream, generally tending towards smaller particles. Cycling of materials and feedback loops prevent this from becoming a simple, straightline phenomenon (Elwood et al. 1983); however, the bulk of all organic matter carried by a stream is ultimately in the dissolved form (Perkins 1974).

Two processes occur shortly after the CPOM enters the water. Solubles leach and enter the pool of DOM. The rate of leaching decreases dramatically after 24 hours (Cummins 1974). Secondly, microorganisms - bacteria, fungi, and protozoa - colonize the surfaces within the first two weeks. Thus the CPOM is reduced to FPOM via abrasion in the moving water and two biological processes, microbial metabolism and feeding (by shredders). Processing rates vary for different species of leaf, needles, and bark; various invertebrates exhibit preferences for the CPOM - microbial complex (Kaushik 1975). Results of many investigators indicate shredders are nutritionally dependent on the microbes rather than the CPOM substrate. Approximately 60 percent of the materials ingested by the shredders is converted to FPOM in the form of feces (Cummins 1974). Some FPOM is imported from upstream; another source is flocculation of DOM. Collectors feed on FPOM; microbes continue to metabolize it; and a portion is exported. These relationships are shown in Figures 4 and 5.

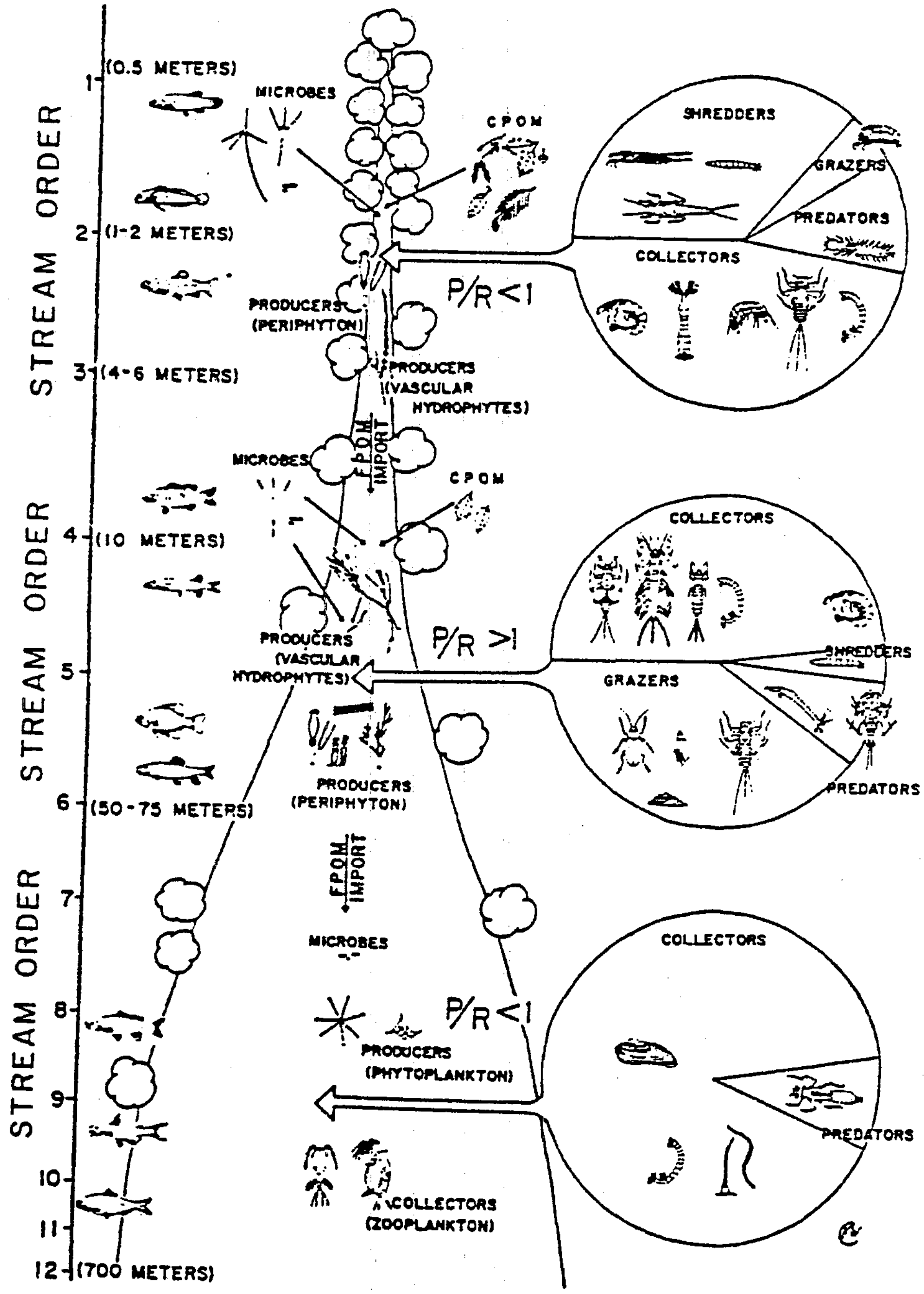


Figure 6. Aspects of the river continuum (redrawn from Cummins (1979). Major primary producers, relative proportions of fauna, photosynthesis-respiration ratios and stream widths are shown in relation to stream order.

The location of components in the riverine system, although not shown in most models, deserves emphasis. Particulates are usually concentrated in bottom sediments, although increased water velocity can resuspend them; DOM is mostly in continuous transport; nutrients are frequently complexed to particulates, especially the FPOM. As mentioned earlier, the quantity and quality (relative proportions) of components vary longitudinally. Relative proportions of shredders, collectors, grazers, and other constituents change as a function of stream order, or distance from headwaters; this is shown in Figure 7.

As emphasized earlier, autotrophs *per se* (algae, phytoplankton, vascular plants) in the system contribute relatively little energy and/or materials. Scrapers are adapted to process attached algae; grazers may feed exclusively on phytoplankton. Because aquatic macrophytes are not heavily grazed, they enter the community processing mechanism primarily after dieback, in the form of CPOM.

Predators feed on shredders, collectors, scrapers, grazers, and each other. They convert a portion of ingested material to biomass, respire some, and recycle much in the form of feces. Nonpredator mortality of fauna results in materials being recycled through the CPOM chain.

A phenomenon that is difficult to depict on diagrams of conceptual models, but extremely important to maintenance of all ecosystems, is timing. This is frequently drawn as a switching mechanism in Odum-type diagrams (e.g. Figure 11). Microbial action occurs year-round, even in cold arctic systems (Cowan et al. 1983; Cummins 1974). The seasonality of autotrophs and insects is well established. Generalized models usually show leaves and other litter entering the lotic system in the fall. However, large, undeterminable amounts of detritus (POM) enter (and exit) systems during every flood. Depending on degree and frequency of flooding, the major

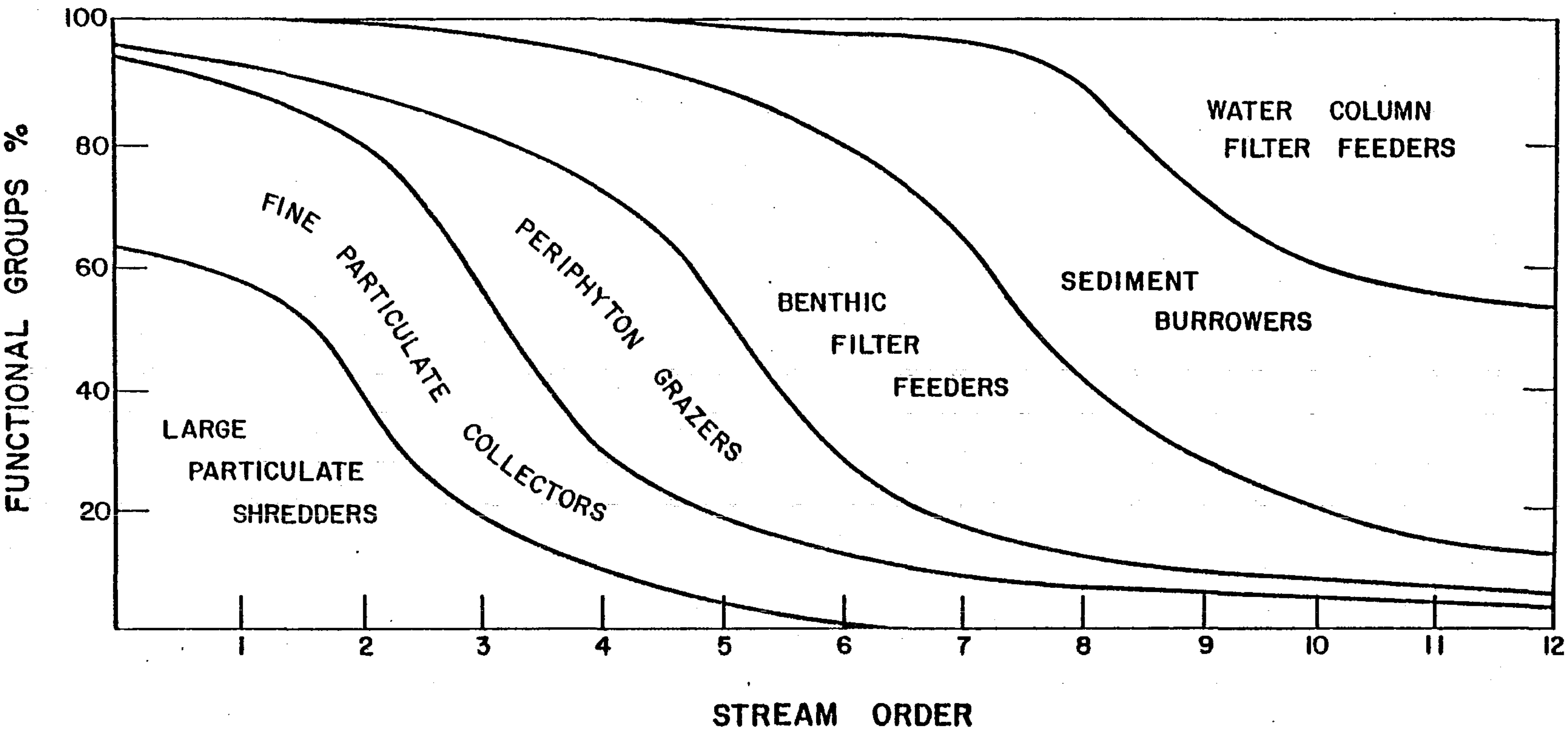


Figure 7. Relative proportions of consumer groups as a function of stream order (redrawn from Vannote 1981).

fraction of a river's annual particulate import and export may occur during a short interval. Thus, flood events - and their timing - are critically important to the lotic system and all adjacent ecosystems.

Riparian

Depending on the nature and purpose of their work, researchers have offered broad and narrow definitions of riparian systems; an ecosystem approach favors the former. Brown et al. (1978) defined riparian ecosystems as wetlands possessing (1) a high water table due to their proximity to an aquatic system or subsurface water, and (2) distinct vegetation and soil characteristics. These systems tend to be elongate, typically paralleling a river. Odum (1978) stressed their extreme variability in structure. Other authors have emphasized that, although they vary greatly in species composition, all riparian systems possess two general characteristics: (1) laterally flowing water that rises and falls at least once per growing season, and (2) high degree of linkage with associated ecosystems (Ewel 1978; Herbst 1978; Klopatek 1978; Merritt and Lawson 1978; Wharton and Brinson 1978). High species diversity, high species density, and high productivity also characterize most riparian sites.

Lateral, pulsed flow of water - in the form of flood events - is the main forcing function (Gosselink and Turner 1978). If this driving mechanism disappears, the system atrophies and/or is replaced. On a long-term basis, flooding maintains a riparian system at relatively early stages of vegetational succession. This phenomenon has been termed pulse stability (Odum 1969), and wetland managers, in an attempt to benefit selected fauna, have long been employing it by controlled alteration of flooding and drawdowns.

The basic organic components in riparian systems (primary producers, detritus, dissolved organics, consumers) are generally comparable to those of riverine systems (Figures 2 and 3). However, primary producers in riparian systems contribute a proportionately larger share of the annual carbon budget. The emergent vegetation functions as an important carbon and nutrient pump, temporarily storing materials and energy until they are flushed by laterally flowing water (Brinson et al. 1983; Klopatek 1978; Wharton and Brinson 1978). As floodwaters recede, they deposit vital soil and nutrients in the riparian system. Studies in other systems have demonstrated a direct relationship of flooding to productivity (Bayley and Odum 1976; Mitsch 1978); studies at this level of detail in northern systems were not encountered during this review. Odum (1978) reviewed the subject and offered a simple model (partly hypothetical, partly data-based) that is reproduced as Figure 8. It indicates that intensity of flooding may be as important as frequency. Only as flooding becomes "abrasive" (removing vegetation completely) does productivity decrease; Ward and Stanford (1983a) concluded that diversity exhibits a similar relationship to periodic disturbances. In his review of development impacts on the Peace-Athabascan River system, Townsend (1975) emphasized the importance of extremes to the maintenance of riparian environments. All researchers are aware of reciprocal interchanges between riverine and riparian systems; many have discussed subsidies offered by both; some have offered evidence that riparian systems can be dependent on nutrients and energy provided during flood events (Klopatek 1978; Wharton and Brinson 1978).

The scientific literature is replete with studies of riparian nutrient budgets in temperate and tropical regions, but detritus and nutrient fluxes in northern riparian systems are at an early stage of study. Cowan and Oswood (1983), investigating riparian systems of a second-order arctic

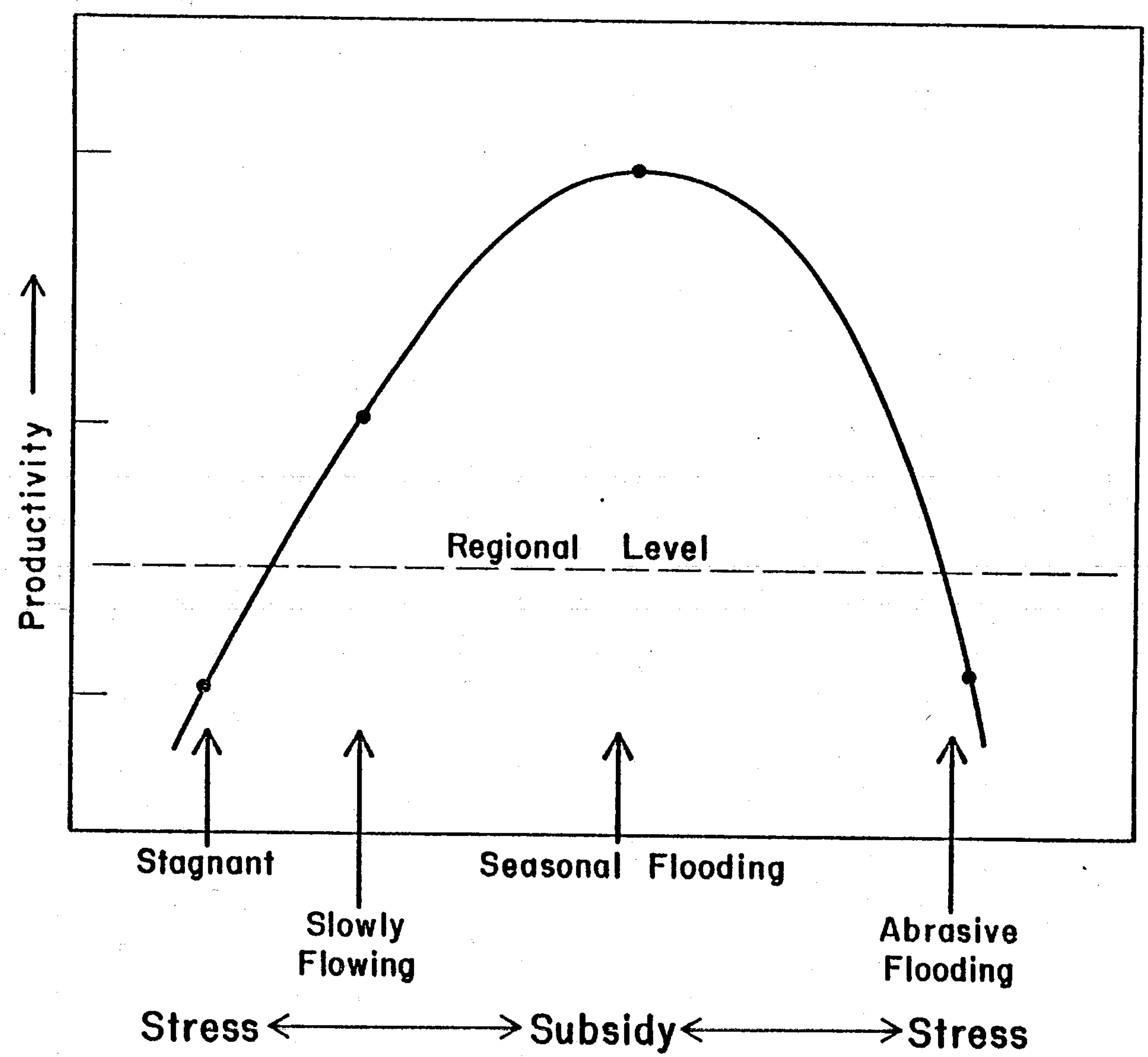


Figure 8. Productivity as a function of flooding gradient (modified from Odum 1978).

stream, reported low levels of detritus input. In a related study, Cowan et al. (1983) found the processing rates of major riparian tree species differed significantly; alder decomposed much faster than birch or willow.

Investigations of structure, function, and productivity of sub-arctic riparian systems are generally lacking. Lee and Hinckley (1982) explained that studies of northern riparian vegetation are still at a descriptive phase because many northern species have broad ecological tolerances, and therefore thrive in many types of sites. Thus categorization and subsequent generalization are time-consuming and difficult. Although it is safe to assume that riparian and riverine systems are strongly interconnected in northern regions, mutual influences can vary with stream order, size of wetland, type of wetland, species composition of wetland, etc. In their review of the sparse literature, Lee and Hinckley (1982) stated that riparian sites of the Pacific Forest Province tend to support the highest species diversity and most complex community structure within all of southeast Alaska. Focusing on bog-forest complexes (muskegs), these authors discussed problems in discerning the general phenomena occurring, but offered a working hypothesis that muskegs may succeed forests or vice-versa, depending on hydrological events.

Consumers in northern riparian systems have received intensive rather than extensive study. Much literature documents the food and cover provided by these ecosystems to anadromous fish and itinerate wildlife. Although the interrelationships exist, the degree of dependence of these consumers on riparian systems is largely unstudied. Ewel (1978) emphasized that insects may be the cardinal link between riparian and riverine systems. A food web study in northern Alaska supports this idea. Schell (1983) concluded birds and fish using the Colville River system of Alaska were dependent on insect larvae to convert peat to a usable form.

Marsh/Estuarine

Because they are located at the junction of fresh and salt water ecosystems, deltaic complexes are in constant dynamic flux. These coastal systems have a greater variety of energy and material sources than riverine or riparian systems. Numerous studies have sought to determine the relative importance of salt and freshwater inputs to maintenance of estuarine ecosystem structure and function. Although researchers have offered sundry generalizations, variation is great, and extrapolations between geographic regions are precarious. Functional aspects of coastal ecosystems are probably more similar than structural aspects.

The structure and function of coastal salt marshes have been amply reviewed; abundant research on these systems continues on the eastern and southern coasts of the United States. However, coastal marshes of the northwest Pacific are typically found at the mouths of large rivers, and resemble freshwater marshes more than saltwater marshes.

The literature supports the thesis that these are detritus based systems. Figure 9 illustrates a typical food web. Most of the POM originates from flora rather than fauna; Odum and Heywood (1978) provided data and a review which indicate freshwater marsh plants decompose faster (and are of higher nutrient content) than plants growing at higher salinities; debates continue over the relative importance of riverine, marsh, and marine sources of carbon. Most workers in relevant systems of the Pacific Northwest agree that riverine processes dominate (Naiman and Sibert 1979; Pomeroy 1977), but seasonal variations introduce a complicating factor. Kistritz (1978) provides a relevant literature review of energy flow through coastal ecosystems, and relates results to the Fraser River

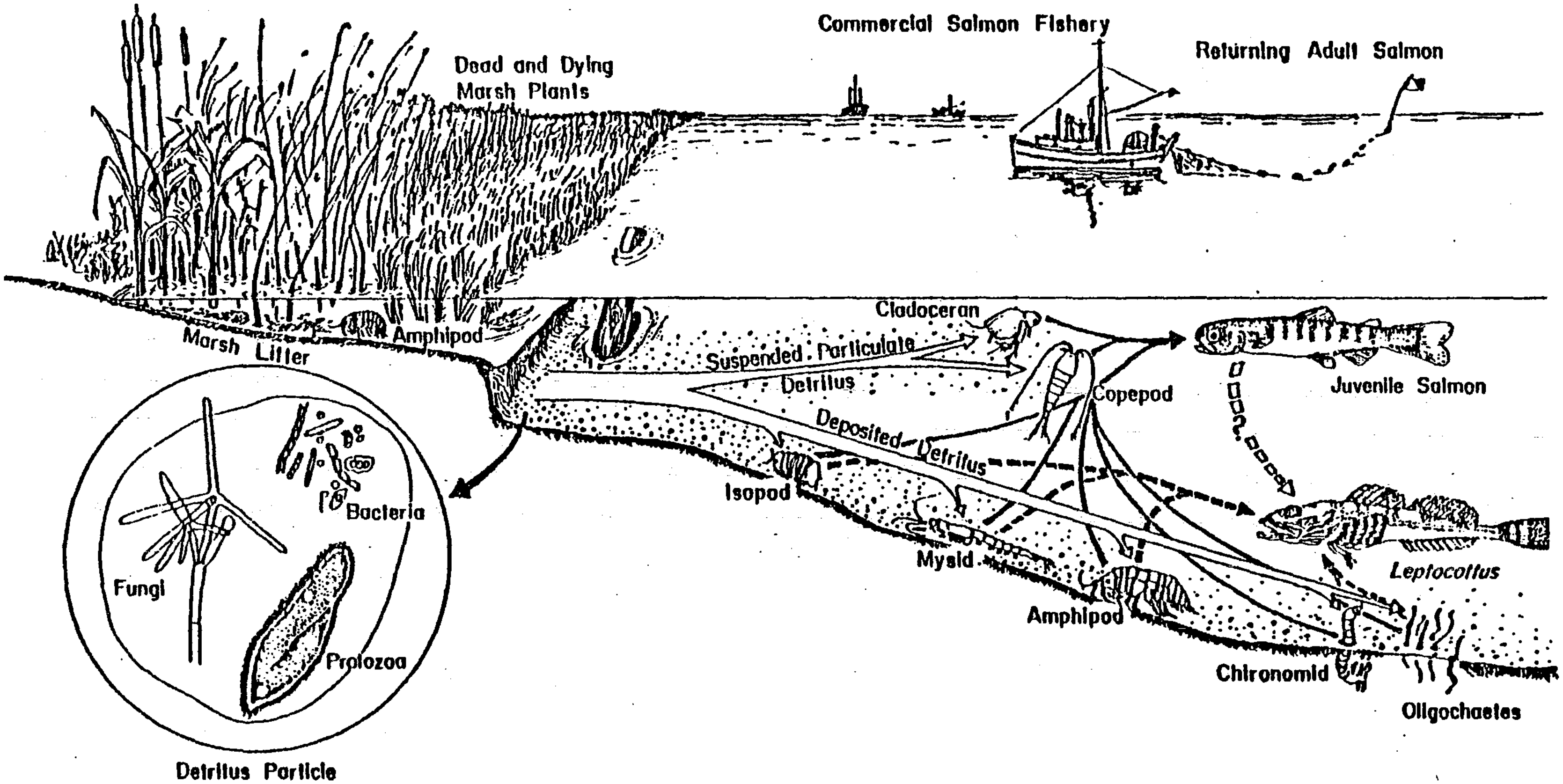


Figure 9. A general detritus-based food web typical of sub-arctic marshes (redrawn from Dorcey et al. 1978).

of British Columbia, a system structurally similar to the Stikine. Detailed discussions of components and interactions can be found in his report and a subsequent vegetation study (Kistritz and Yesaki 1979).

A delta marsh ecosystem originates as a series of deltaic islands dissected by numerous channels. Formation processes have been thoroughly described (Kellerhals and Murray 1969; O'Neil 1949; Pestrong 1965); the phenomena can be viewed simplistically as simultaneous deposition and subsidence, with longshore current modification near the delta face. As a delta aggrades, vegetation zones develop and succession occurs as environmental constraints allow. Proceeding from upland toward low tide mark, typical zones are high marsh, low marsh, common spikerush, and mud flats. These appear to reflect stages of succession, as is the case in other marsh systems. The number of zones, the duration of each, and species compositions are geographically variable and highly dependent on local edaphic conditions and elevation. Differences of 10 cm in marsh elevation can result in noticeable shifts in species dominance (Kistritz and Yesaki 1979). Carex lyngbyaei, a sedge, typically dominates low marsh (frequently in pure stands), and is a principal component (mixed with grasses and forbs) of high marsh. Eleocharis palustris dominates the spikerush zone, and various diatoms predominate in the mud flats (del Moral and Watson 1978; Pomeroy 1977).

Simplified and expanded conceptual models of the deltaic complex are shown in Figures 10 and 11, respectively. The main components of the system are water storage, sediment, nutrients, salt, detritus, primary producers (phytoplankton, benthic algae, emergents, grasses), primary consumers and secondary consumers. Sediment, nutrients, detritus, salt and gases are moved to and from adjacent systems by flowing water, the most important forcing function.

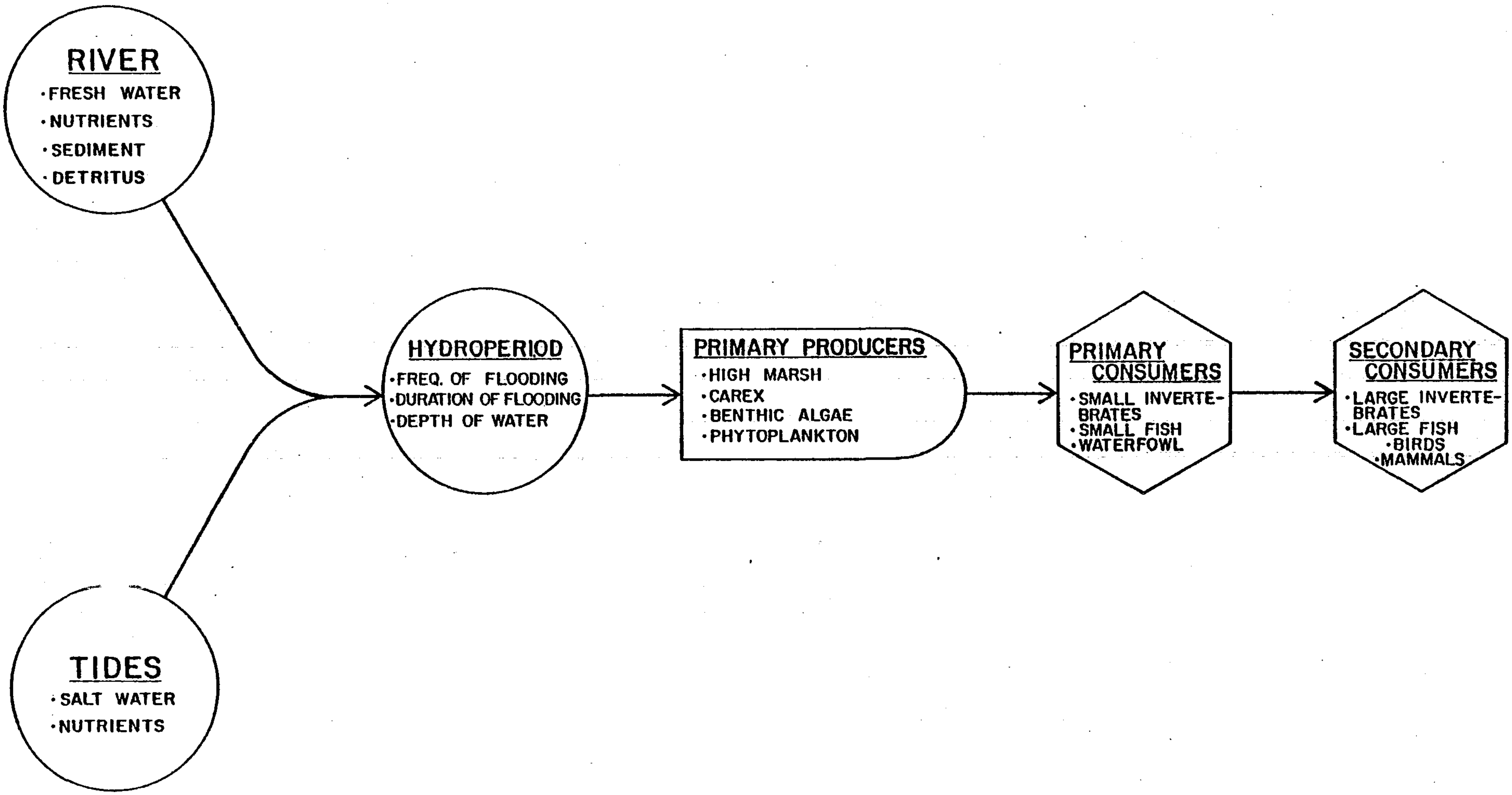
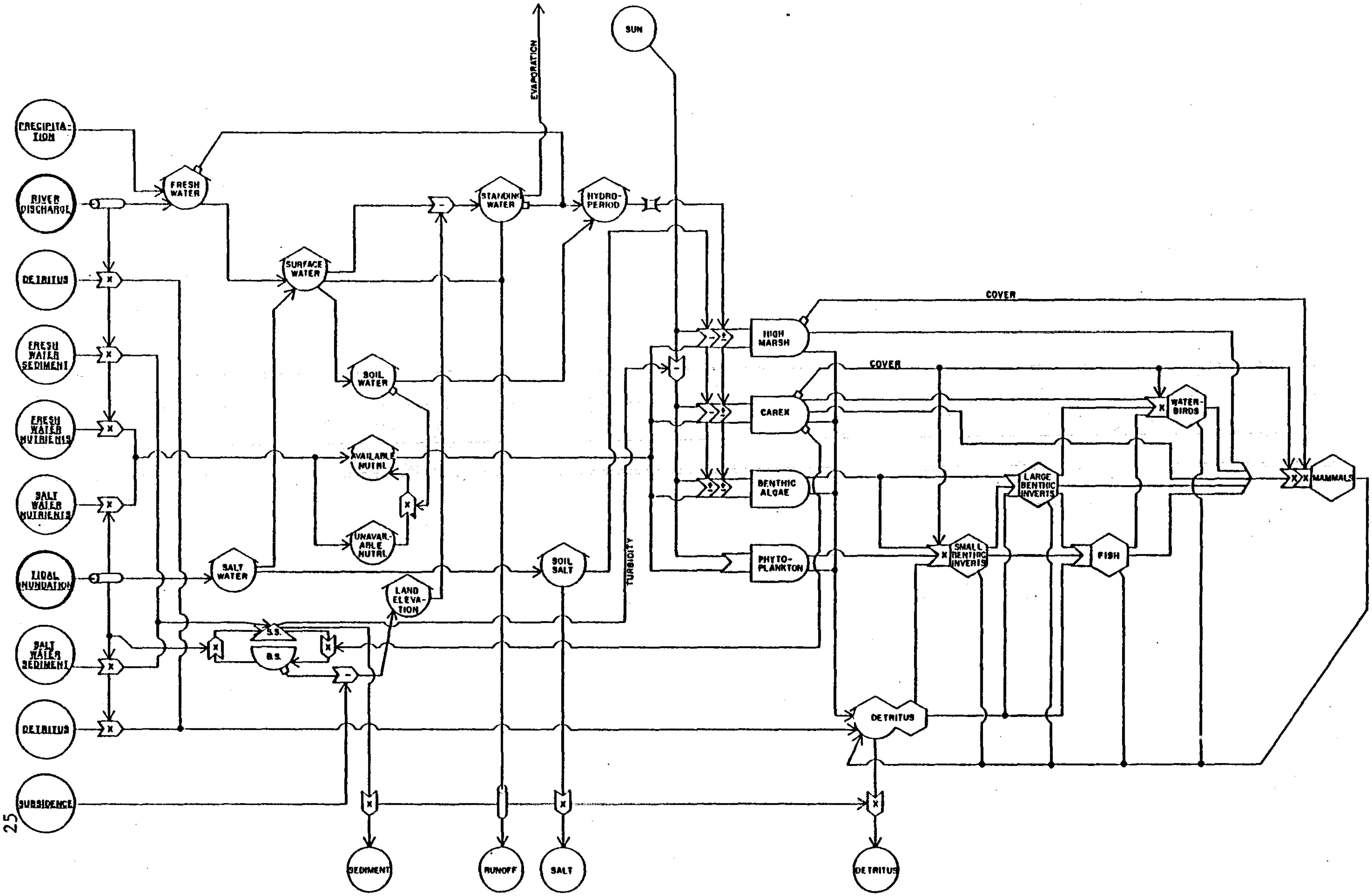


Figure 10. Major components and forcing functions in the Stikine River delta/estuarine ecosystem.

Figure 11. Conceptual model of energy flow in the Stikine River delta ecosystem.



Water Fluxes

Riverine flows and rain are primary sources of fresh water; tidal fluctuations of approximately 6 m provide salt water. The few investigations of systems in the northwest Pacific indicate carbon, and possibly nutrients, are primarily imported via fresh water (Kistritz 1978; Naiman and Sibert 1979; Parsons et al. 1970; Seki et al. 1969). The timing of these water flows are critical to the maintenance of the marsh/estuarine complex. A classical example is the dependence of aquatic food chains on spring blooms; in the case of the Stikine complex, this may extend through eulachon to harbor seals and bald eagles.

Water inputs to the system follow one of three possible pathways. They may percolate into macropore and micropore spaces of soil, if the soil is saturated; they may contribute to the storage of standing water; they may exit the system as runoff.

Sediment

The sediment pool may be partitioned into two components - bottom sediment and suspended sediment. Sediments moving into and out of the system are suspended in water and are proportional to the rate of flow of water. The Stikine's average annual discharge of approximately 1500 m^3/sec carries 16 million metric tons of sediment (B.C. Hydro 1982). The nutrients complexed with bottom sediment contribute to the nutrient pool in the system. Accumulation of bottom sediment leads to an elevation increase. Progradation rates for the Stikine delta are unknown; the Fraser River, which carries about 18 million tons annually, appears to be building its delta (vertically) about 1-2 mm/yr over the long term (Kistritz and Yesaki 1979; Moody 1978). However, localized accretion rates of 3.5 cm/yr have been documented (Burgess 1970). Dipert (1975), working on the Stikine delta, postulated that windblown materials can accumulate in localized areas at rates approaching 45 cm/yr.

Suspended sediment directly affects flora and fauna. Turbidity decreases primary productivity by decreasing the light energy available to primary producers. Suspended sediment can interfere with vision, respiration, and feeding of consumers.

Nutrients

Significant nutrient sources in the marsh-estuarine complex include allochthonous dissolved organics and inorganics, detritus, and bottom sediment. Relative contributions of each can vary geographically, but the dominance of riverine inputs has been established. Phillips (1972) stated that on a world-wide average, fresh water contains 10 times the concentration of dissolved organic matter as sea water.

Unavailable nutrients can be converted to available nutrients by two main processes. Bacteria and protozoa transform complex organic molecules to simple usable forms; phosphate and ammonia are usually considered the most important nutrients involved (Richardson et al. 1978). In addition to microbes, submergence affects the availability of nitrogen, phosphorus, iron, calcium, magnesium, manganese, potassium, sulfate, and chloride by changing the oxidation-reduction systems and microbial populations that act. The reduced forms of inorganics are generally more available to plants than the oxidized forms (Brupbacher et al. 1973; De Laune et al. 1976; Kistritz and Yesaki 1979).

Primary Producers

Sedges and grasses are the main contributors to carbon flow in the marsh. Productivity rates for the Stikine delta are unknown; study sites in similar systems have yielded ranges of net production as follows: high marsh, 450 g $C/m^2/yr$; low marsh, 450-900 g $C/m^2/yr$; benthic algae, 114-150 g $C/m^2/yr$; phytoplankton, 10-500 g $C/m^2/yr$ (Moody 1978; Pomeroy 1977; Stockner and Cliff 1976; Yamanaka 1975). Hill and Webster (1983) and Pomeroy (1977) emphasized that it may be more prudent to examine the seasonal timing of each component's contribution than the absolute amount of biomass. Primary producers are differentially regulated by water fluxes, sediment, salinity, temperature, and nutrients. Complex, poorly-understood interactions dictate the vegetation composition available to consumers at any given site.

In addition to producing food for consumers, the emergent vegetation provides cover. Numerous reviews discuss how the marsh-estuarine complex provides additional subsidies to conspicuous animals such as waterbirds and fish. Less studied, but obviously important to the food chain, is cover provided to invertebrates such an amphipods. These crustaceans, providing a vital link in the food chain in estuaries of British Columbia (Levings 1980), are strongly associated with rhizome mats of _C. lyngbyaei_ (Pomeroy and Levings 1980).

Consumers

Primary consumers in the system may be categorized as terrestrial or aquatic. Small fish and invertebrates, feeding primarily on detritus and phytoplankton, comprise the bulk of the latter category. Sculpins, salmonids, flounders, shrimp, amphipods, bivalves, and various worms are noticeably abundant in systems similar to the Stikine (Kistritz 1978;

Kistritz and Yesaki 1979; Levings 1980; Levings and Coustalin 1975; Levy and Levings 1978; Levy and Northcote 1981a; Levy and Northcote 1981b). Preliminary surveys indicate these guilds are present in the Stikine system (Beak 1981), but complete studies are lacking. The information presented by the above authors and others (e.g. Moody 1978 and Pomeroy 1977) leaves little doubt that these systems are detritus-based.

Waterfowl and mammals consume primary producers directly. Dabbling ducks and geese feed preferentially on seeds and rhizomes, respectively of Carex lyngbyaei (Burgess 1970; Burton 1977; Hughes and Young 1982; Moody 1978). Diving ducks utilize numerous arthropods and molluscs.

Secondary consumers that rely heavily on aquatic species include salmonids, flatfishes, crabs, amphibians, mammals, and some birds. Important tertiary consumers include hawks, eagles, and bears.

REVIEW OF ENVIRONMENTAL EFFECTS OF HYDROELECTRIC DEVELOPMENT

Man, to enhance his well being, started controlling natural flows of water 2000 years ago. As more and larger dams were constructed, undesirable effects became more widespread and noticeable. Investigators subsequently documented many impacts; today the scientific literature abounds with reviews of regulation effects. Some treatments of the subject are worldwide in scope; others are geographically or climatically restricted. Some present only general discussions of altered ecological processes; others discuss measured effects of a project on species of interest. Some are restricted to effects at a reservoir, others with tailwater zones or estuaries. Processes and chains/networks of cause-and-effect relationships are quite complex, and it is difficult to amalgamate and present regulation effects in a lucid, concise manner. Stanford and Ward (1979) stated that comprehensive documentation of hydroelectric effects on specific ecosystems is unavailable. A major reason is that delayed impacts occur over long periods and at distances greatly removed from a project site; large sums of money are required to study/report effects on an entire ecosystem. Although the ideal of holistic documentation may not be attained, these authorities believe the systems approach is prudent because predictions of effects are primarily hampered by lack of knowledge of functional processes (structural changes are virtually site-specific). Ward and Stanford 1983b stated "a major impoundment at any position on a river system will directly and indirectly affect all ecological aspects of the downstream lotic ecosystem at some level of resolution," and strongly suggested we examine functional responses on at least the daily and seasonal time scales. Their idealized curves of hypothesized changes in 16 parameters resulting from dams on upper, middle and lower reaches of rivers are presented in Figure 12.

Because structural changes in ecosystems are site-specific and thus difficult to predict accurately, a set of documented changes from existing projects is not a viable substitute for research. Rather, a comprehensive review should be viewed as an attempt to define the scope of possible effects. Resultant generalizations should provide assistance in determining areas of concern and selecting specific problems for investigation.

To provide organizational framework to our selective review of the overwhelming literature dealing with regulation impacts, we will relate examples to driving forces and components of affected ecosystems. This practice facilitates tracing the effects through many complexities of structure and time. Spatial partitioning of effects (reservoir, proximal, distal) provides an additional organizational aid to our review.

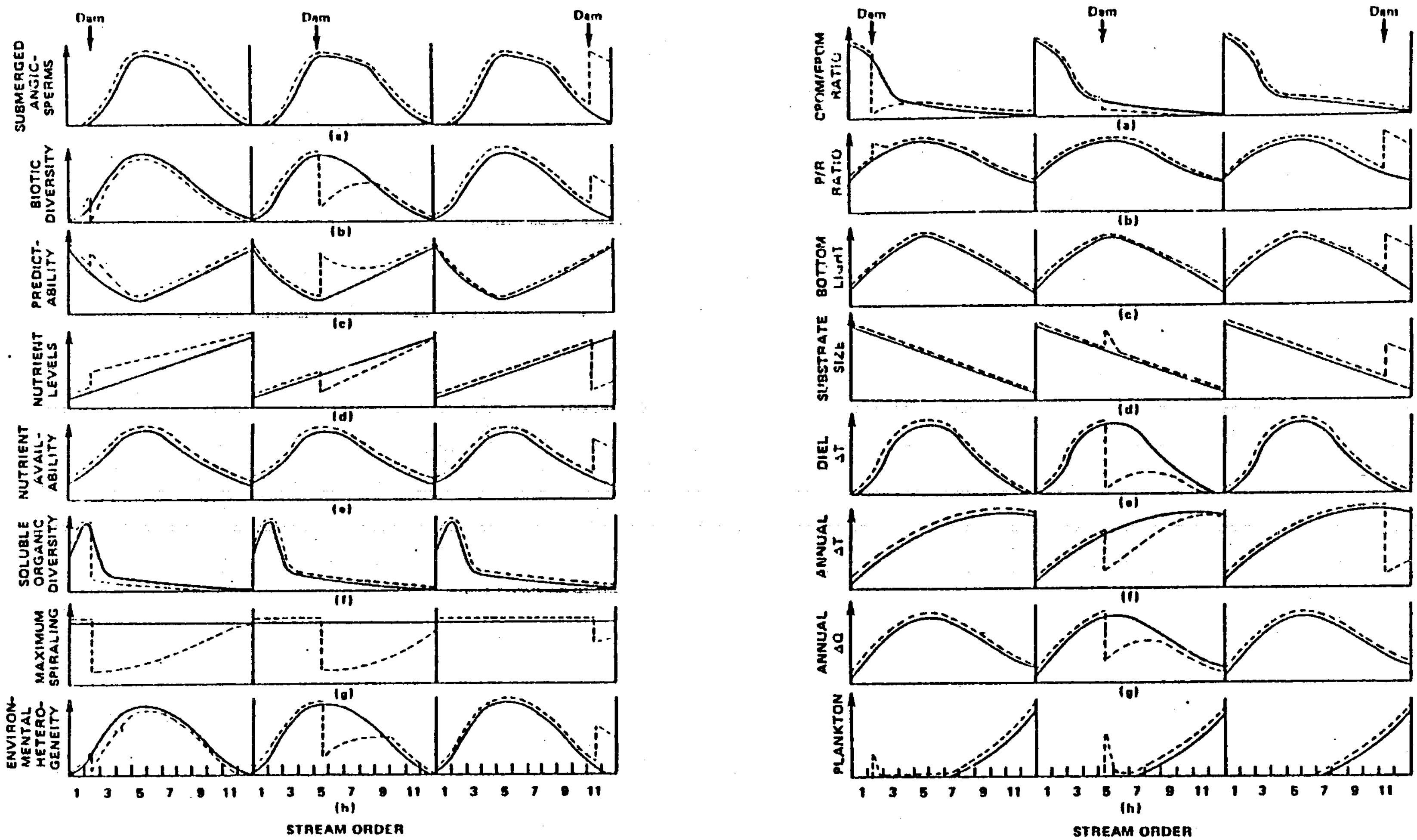


Figure 12. Hypothesized dam-induced changes in parameters of stream ecosystems as a function of stream order (modified from Ward and Stanford 1983b). Dashed lines show postulated alterations.

Reservoir Effects

Creation of a reservoir is aptly viewed as replacement of ecosystems rather than modification of a river. Predictably, the environment directly affected by the project undergoes drastic changes. Review papers present examples and thoroughly discuss the typical phenomena (and mitigation) that can occur during filling and for decades thereafter. Because natural resource agencies in Alaska are primarily concerned with subsequent events, our survey is confined to those generalized changes that lead to downstream effects. Readers more concerned with reservoir and upstream impacts will gain insight from Geen (1974), Jassby (1976), Baxter (1977), and Baxter and Glaude (1980).

A dam must block water flows - at least during the filling process. Suspended sediment settles from the quieter waters, and nutrients are leached from silt, newly-inundated bed materials, and submerged vegetation. Thus the damming typically leads to a temperature-stratified lentic ecosystem, initially rich in nutrients. Primary producers flourish, a benthos develops, and rank food networks are established - particularly if game fish are abundant or introduced. Following an initial period of high productivity (lasting several years), trophic depression typically occurs, primarily the result of reduced and/or buried nutrients and benthos (Jassby 1976). The maturing reservoir system may approach equilibrium and vascillate relatively little, continue pronounced cycling, or undergo erratic fluctuations in carbon and nutrient flows. The pattern is highly dependent on management practices and natural events that are not predictable.

The "quality" of reservoir water, including suspended sediment loads, is dependent on these same unpredictable factors. Concentrations of nutrients, toxics, and dissolved gases will change through time; thus predictions of concentrations are somewhat futile. However, one generalization that appears valid is that hypolimnetic waters typically contain higher concentrations of plant nutrients (and toxics) than epilimnetic waters.

Stikine project proponents have initiated reservoir modeling studies, but to date the efforts have focused solely on temperature effects (B.C. Hydro 1983a). Biological and chemical simulations require emphasis in the future.

Downstream Effects

This section deals with effects present from the tailwater zone to the delta/estuarine complex. Alaskan resource agencies are acutely concerned with phenomena in this region because they directly and indirectly affect ecosystems and components located inside the United States' border.

Water Flows

The establishment of a new regime of water discharge can lead to the greatest impacts on downstream systems. Regardless of the details of spillway management, the annual water discharge pattern is more regular than the unregulated condition - typically involving a decrease in amplitude, frequency, and duration of floods, and an increase in diurnal variation (amplitude and frequency). In general, regulation leads to greater-than-natural discharges in winter (due to power demands), and lesser-than-natural discharges during other seasons (due to reservoir filling).

Reservoir filling and operation schedules for the Stikine River development are continually modified; however, latest estimates (Jones 1983) indicate the above altered pattern in seasonal flows will occur. Jones' summary (1983) states that diversion closure in October would interrupt 100 percent of flows at the damsite for up to 20 hours. During reservoir filling (1 February through 30 April), flows immediately downstream of the damsite will be reduced by 90 percent. From 1 May through 31 October, downstream releases will be reduced by 70 percent. Exact operation schedules are highly dependent on power demands, and reliable estimates of the latter are not available.

Large reductions in Stikine River flows are attenuated by downstream tributaries, but supplemental water releases from dams may be necessary to ensure fish access to spawning grounds. Even though operation schedules maintain flows above the historic minima, highly significant changes can be expected because frequency and/or duration of these minima are much greater than with natural conditions. For example, one downstream station (Stikine River above Butterfly Creek) may experience a 15-fold increase in the number of days that flows are below 10 percent of the mean annual discharge (Jones 1983).

Stream Channels

Loss of high flows tends to change the morphology of downstream channels. Depending on specific topographic features, braided patterns may increase or decrease. Those side channels that only flow during extreme floods will tend to atrophy, thereby decreasing spawning and rearing habitat for fish (Geen 1974; Holden 1979). Should the loss of braided networks be severe, several other problems can arise: (1) boating and recreation will be hampered, (2) spawning, nesting, and rearing habitats for fish and wildlife (especially waterbirds) will decrease, and (3) predators may access previously unreachable islands (Kellerhals and Gill 1973).

Expected changes in morphology of the Stikine River have been qualitatively described (Jones 1983): (1) many secondary channels will fill in and be colonized by vegetation; (2) deltas will develop at tributary confluences due to reduced ability of the mainstream to transport sediment; and (3) active channel widths will gradually diminish.

Data have been collected from a test reach on the Stikine to aid in predicting the availability of suitable habitat for fish and wildlife as a function of discharge (B.C. Hydro 1983b). Completed analyses will only be pertinent to those areas for which the test reach is representative after regulation; effects on areas isolated from mainstream influence must be addressed separately.

Daily Fluctuation

Sutcliffe (1973) discussed the importance of considering the direct effects on biota of changes in amount and timing of discharge. Strongly fluctuating flows of tailwater regions can scour attached phytobenthos, sediment, and burrowing fauna (Lowe 1979). Unattached primary producers immediately downstream from a dam may increase or decrease, depending on the balancing of turbidity flux, nutrient decrease, temperature change, and other parameters. Production of reservoir plankton tends to compensate losses to varying degrees (Baxter 1977). These effects will dissipate along the downstream continuum as tributaries buffer the extremes.

Benthic diversity usually decreases, but biomass increases, immediately downstream from a scour zone. Presumably, stresses eliminate some species, and those remaining flourish as a result of decreased competition (El Shamy 1977; Spence and Hynes 1971a).

Baxter (1977) concluded that daily fluctuations in water levels are less important to fish than long-term alterations in flow because spawning-site selection typically requires days.

Most short-term flow changes in the unregulated Stikine system are less than 25 mm/hr. A new operation scenario is being devised to avoid exceeding this arbitrary rate (Jones 1983).

Seasonal Fluctuation

Changes in seasonal patterns of discharge can lead to alterations of migration patterns. Delayed spawning migration of a few days can result in a major decrease in spawning efficiency of fish (Geen 1975). Altered migration patterns of birds are discussed in Heglund and Rosenberg (1984).

In situations where ice-out is hastened by hydrostatic pressure, decreases in spring flows will tend to prolong winter conditions. The availability of habitats utilized by various wildlife species, including migrating waterbirds, may be delayed. Ice-scour, which helps maintain early successional stages of vegetation along channel corridors, will be reduced (Gill 1971; Kellerhals and Gill 1973).

Decreases in flow rates of a very small stream in Idaho led to unexplained increases in insect drift (Minshall and Winger 1968); the researchers postulated respiratory stress, decreased living space and other causes. Radford and Hartland-Rowe (1971) reported similar findings in two larger streams in Alberta; subsequently, they concluded increased insect drift resulted from <u>either</u> decreased or increased flows (Radford and Hartland-Rowe 1972). Depending on the timing of altered flows, this effect could benefit fish and other consumers located downstream. Studies of insect community structure are noticeably lacking in the Stikine systems.

In a review of potential impacts of damming the Fraser River in British Columbia, Geen (1975) explained that an increase in winter/spring flow rates could enhance salmonid egg survival; however, smolts may arrive at the estuary before zooplankton are abundant. Although increased flows could favor phytoplankton growth, decreased temperatures might prevent zooplankton from utilizing them. This may be detrimental to zooplankton feeders, but the energy would not be lost to the ecosystem because it would ultimately be available to the benthic community.

Predictions of changes in Stikine River seasonal flows are seriously hampered by lack of long-term data. For example, the United States Geological Survey gage "near Wrangell" (actually about 10 km upstream from the river's delta) has only several complete years of records. Five-year or longer "flows of record" must be estimated by various formulae (Beak 1981). Given these flow estimates and current operating schedules, a delay of two weeks is expected in the rising limb of the Stikine hydrograph, and the flood peak near the estuary would be delayed by one month (Jones 1983). Ice-out and scouring effects are yet to be addressed; resultant changes in plankton blooms also require attention.

Flooding

As stressed earlier, riparian systems are dependent on flood events to varying degrees. Decreases in flooding frequency and amplitude curtail the exchanges of materials and energy between riparian and riverine ecosystems, and lead to changes ranging from upstream migration of angiosperms (Lowe 1979) to total ecosystem replacement (Dirschl 1971; Walker 1979).

A frequently-discussed example of drastic changes involves the Peace-Athabascan wetland complex in Alberta. The dynamics of succession relative to flooding has been thoroughly reviewed (Fuller and La Roi 1971;

Peace-Athabascan Delta Project Group 1973; Stevens 1971). In summary, the encroachment on Carex meadows by grass and shrub communities led to a decrease in carrying capacity (food and cover) for waterfowl, small mammals, and bison. Fisheries were negatively impacted also (Dirschl 1971; Peace-Athabascan Delta Committee 1970; Peace-Athabascan Delta Project Group 1972; Stanford and Ward 1979; Townsend 1975). Similar detrimental effects have been predicted or documented in many other regions: British Columbia (Geen 1974), Northwest Territories (Gill 1973), France (Decamps et al. 1979), Africa (Davies 1979), and Australia (Walker 1979).

When riparian systems cease to function, subsidation of the river is eliminated. Effects are transmitted through food webs, and the result can be decreased fish production (Baxter 1977; Stanford and Ward 1979).

A more direct effect of altered flooding regimes on consumers was noted by Williams and Winget (1979). Beaver dams, which normally were demolished by floods, persisted following regulation. Waterways remained blocked to nutrient flows, carbon flows, and fish migration.

Post-regulation flooding regimes on the Stikine River have been summarized (Jones 1983); the following estimates are taken from his report. The magnitude of flood events at Telegraph Creek, approximately 50 km from the Stikine damsite, would be reduced an average of 50 percent (range = 47-76 percent). Near the estuary the magnitude of spring floods would be reduced an average of 17 percent (range = 8-31 percent); fall flood peaks would be reduced an average of 5 percent (range = 0-11 percent). Under natural conditions a flood of at least 4750 m^3/s occurs every year; under regulated conditions this rate approaches 4000 m^3/s, a reduction of 16 percent.

In addition to reducing the magnitude of floods, regulation also decreases the frequency and duration of such events. For example, current schedules result in a 41 percent decrease in frequency of a discharge of 4000 m^3/s near the estuary; duration of such flows is reduced 60 percent.

The consequences of flooding regime changes to flora and fauna have been identified as important subjects, but quantitative investigation on the Stikine River is lacking.

Sediment

All dams trap a large proportion of the upriver sediment load. The relatively sediment-free water immediately downstream from a dam has a greater capacity for carrying sediment than prior to regulation. To seek a new equilibrium, erosion of riverbeds can occur up to 145 km downstream (Pretious 1972; Simons 1979) and impart direct and indirect effects to biota.

Should net turbidity be decreased, phytoplankton may increase, and thereby benefit consumers such as insects and fish. Geen (1975) warned that decreased turbidity (increased visibility) could also allow greater predation of these same consumers. The net effect is site-specific and unpredictable.

Quantitative predictions of sediment phenomena of the Stikine River are seriously hampered by (1) relatively sparse and short-term sediment data, and (2) great year-to-year variability in sediment transport. Moreover, levels of suspended sediment are largely controlled by factors other than river discharge (Beak 1982). Jones (1983) listed several factors that influence the suspended sediment load downstream of dams: (1) reductions due to reservoir retention (range = 87-98 percent), (2) reductions due to delta building at mouths of tributaries, (3) reductions due to deposition in secondary channels, and (4) variable, unpredictable changes due to reduced overbank flooding. Although only one of these factors has been quantitatively estimated, it is important to note they all can lead to decreases in downstream suspended sediment.

In 1983, B.C. Hydro initiated a reconnaissance study of sedimentation effects on vegetation along two transects. If a hydroelectric project occurs on the Stikine and this vegetation study continues to monitor changes, results may allow future predictions of vegetation alteration in similar systems subject to hydroelectric development.

Nutrients

Phosphorus, nitrogen and other nutrients commonly associated with particles in complexed forms are trapped behind dams. Newly-generated, suspended nutrients are quickly utilized by primary producers in the reservoir; downstream riverine and riparian systems are therefore starved for nutrients. Deterioration of productivity has been described for the Mackenzie and Peace-Athabascan River systems (Baxter 1977; Dirschl 1972; Kellerhals and Gill 1973). Depending on the magnitude of decrease in nutrients, effects may extend to production in marine systems (discussed later).

Nutrient budgets in the Stikine system have received little attention; no data have been presented to date.

Organic Matter

Reservoirs also act as sinks for DOM and POM; the latter includes a range from detritus to logs. The <u>quality</u> of DOM and POM can be expected to change also, and primary-producer distribution and abundance will reflect net effects (Cummins 1979). Consequences of such changes may be evident in the macroinvertebrate community (Spence and Hynes, 1971a). Webster et al. (1979) modelled chains of events through consumers, and concluded the interruption of POM by dams may profoundly affect downstream food webs.

Levels of organic matter have not been reported for the Stikine River system, and discussions of alterations due to regulation are noticeably lacking. Macroinvertebrates, which depend on DOM and POM, have not been described for natural conditions; therefore, predicted changes in macroinvertebrate communities as a result of project development are presently not possible. This is a serious void since preliminary studies have shown that insects are a major item in salmonid diets (National Marine Fisheries Service 1982).

Temperature

Downstream temperature changes are also a result of numerous site-specific, unpredictable factors. In general, projects tend to raise normal water temperatures in cold seasons and lower them in warm seasons. Ward and Stanford (1979) reviewed studies that indicate such an increase in thermal constancy is deleterious to most biota. If the areal extent of the reservoir and other conditions are conducive, changes in climate of the region can occur (Baxter 1977).

Much of the scientific literature consists of studies of dam-induced temperature changes on single species or guilds. Spence and Hynes (1971a, 1971b) concluded that the absence of four species of cyprinid fish and changes in species composition of insect larvae were the result of temperature effects. Lehmkuhl (1972) reported that temperature changes explained the lack of invertebrates 100 km downstream of a dam. He later provided a complete review of temperature-change effects on development and reproduction in insects (Lehmkuhl 1979). Ward and Stanford's (1979) chart emphasizing the complexities of thermal modifications on zoobenthos is shown in Figure 13.

McCart (1983a) provided a relevant starting point for approaching the vast literature of temperature effects on salmonid reproduction and growth. Information contained in that report will not be repeated here, but it should be stressed that the rate of change of temperature can be as important to all biota as the absolute magnitude of change.

Estimates of average temperature deviations for Tanzilla, a downstream site on the Stikine River, approach 4°C (B.C. Hydro 1983a). Studies of ramifications of these temperature changes are primarily restricted to fish. McCart (1983b) reported that results of temperature effects on Stikine salmonid development may be available in late 1984.

Miscellaneous

Most review papers mention gasbubble disease in fish, which results from gaseous supersaturation of waters as they traverse the spillway. Management practices can reduce the concentrations of gases, and levels approaching saturation are typically regained short distances downstream. Collins (1976) presented a general discussion of the problem and stated that 110 percent saturation is a rough threshold for lethality.

Incidence of infectious diseases transmitted via snails and/or mosquitoes has increased following impoundment (Baxter 1977); however, those diseases transmitted by black flies may decrease due to loss of breeding habitat (running water).

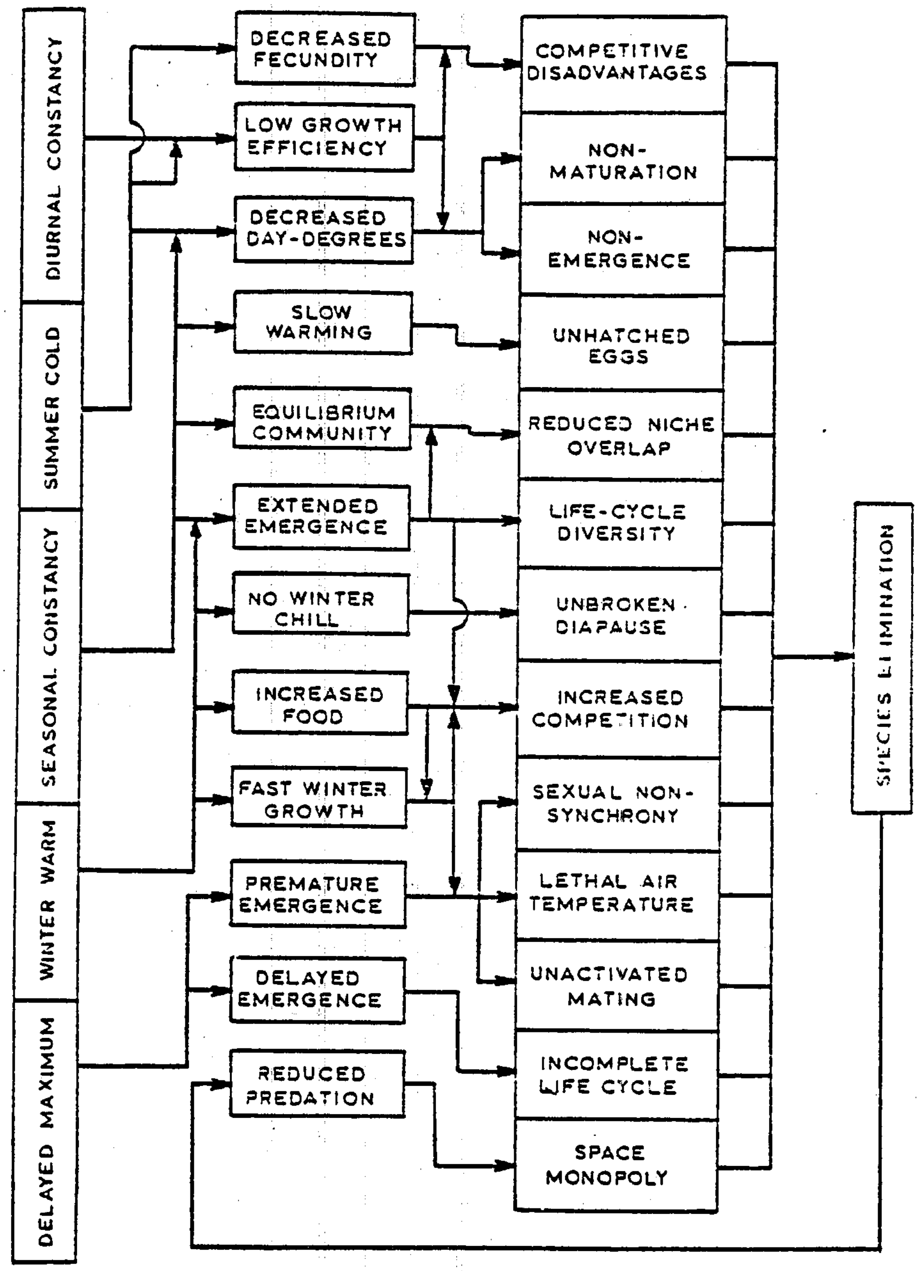


Figure 13. Potential dam-induced thermal effects and interactions on stream zoobenthos (modified from Ward and Stanford 1979).

Inducement of seismic activity has been the topic of some study. In those cases thoroughly analyzed, seismic activity only increased in previously-weakened zones - it appears that impoundments are not capable of exerting the geophysical effect in toto (Baxter 1977).

Delta/Estuarine Effects

Many effects occurring in these distal complexes are extensions of those reviewed in the previous section. As discussed earlier, delta/estuarine complexes are usually detritus-based and dependent on pulse events of riverine systems. Their location and production of valuable resources dictate intense interest by resource agencies in the United States and Canada.

Water Flows

Dam-induced changes in daily fluctuation may not be discernible at the estuary, depending on the relative contribution of tributaries to total flow. Therefore, estuarine consequences of diel changes will be indirect and primarily the result of site-specific, unknown alterations in upstream biota previously discussed.

Changes in seasonal patterns have a greater capacity for directly affecting delta/estuarine complexes. Neu (1975) postulated that 33-50 percent reduction in discharge of the St. Lawrence River profoundly affected the biological balance of the estuarine system via alteration of currents. Baxter and Glaude (1980) reviewed impacts of such changes, and stressed that ramifications are always site-specific and generalities are tenuous (e.g., the degree and effects of changes in salt water intrusion of the Stikine River).

Migrations of fauna may be directly affected by modification of seasonal flows. Effects on salmonids and eulachon have been discussed (Franzel and Nelson 1981; Geen 1975); presumably, shellfish could be similarly affected.

Effects on ice-out (previously discussed) may extend to the estuary. Greater-than-normal discharge in late winter/early spring could hasten breakup and availability of wetland and delta habitats to biota; the converse is also valid. The timing of availability is critical to all migrating biota; effects on birds are discussed in Heglund and Rosenberg (1984).

The most significant impacts of discharge alterations to the functional integrity of an estuary are likely indirect, and result from decreases of imported materials - primarily sediment, nutrients, and detritus. A cardinal question is rarely addressed: How much change can be tolerated by ecosystems? In a broad review of development impacts in Russia and elsewhere, Rozengurt and Haydock (1981) stated "direct experience and published results of the effects of water development abroad all point to the inescapable conclusion that no more than 25 to 30 percent of the natural outflow can be diverted without disastrous ecological consequences ensuing."

Because numerous unregulated tributaries exist downstream of proposed dams, daily fluctuations are not expected to persist at the Stikine estuary. However, upstream effects of daily fluctuations could result in measureable changes near the estuary. Decreases in upsteam primary producers and benthos would result in decreased CPOM, FPOM, DOM and nutrients entering the delta/estuarine complex. These components have not been examined in Stikine River investigations.

Changes in seasonal flows at the Stikine estuary have been estimated (Jones 1983; Beak 1983): winter increases average 100-200 percent, spring decreases average 17 percent (range = 8-31), and decreases in fall floods average 5 percent (range = 0-11). Probably more important than volumes of flows are the changes in timing, frequency and duration of flood events. The annual spring/summer flood peak on the delta may be delayed by one month. A moderate discharge (e.g. 4000 m^3/s) may be reduced 41 percent in frequency and 60 percent in duration (Jones 1983). Such changes can alter the dynamics of detritus-based estuarine systems. Although preliminary estuarine grab sampling occurred (Beak 1981), benthic and neritic components have yet to be adequately described. Only after such descriptions exist can reasonable predictions concerning top consumers be generated.

If Stikine eulachon migrations are tied to seasonal flows, disruptions of food chains can occur. Effects could be transmitted to harbor seals and bald eagles, important predators of the delta/estuarine complex (see Part II of this report).

The Stikine delta front remains ice-free because of six-meter tides; therefore, delays in ice-out would not be expected to affect consumers using these habitats in the spring - primarily migrating waterbirds (Part II of this report). However, ice conditions in areas not subject to tidal influence are variable and unpredictable (Beak 1982). Wildlife in these regions (e.g. moose, wolves, bears) may be affectd by changes via two mechanisms: (1) solid ice provides a relatively easy corridor for travel, and (2) food items may be unattainable under ice.

Sediment

Maintenance of a viable delta ecosystem requires a supply of sediment to counteract the processes of subsidence and erosion. As described earlier, vegetation zones and succession are directly affected by elevation of the delta. Extreme losses of coastal habitats due to sediment starvation have been documented in the eastern Mediterranean Sea (Aleem 1972; George 1972) and the Gulf of Mexico (Morgan 1972).

Turbidity directly and indirectly affects the biota of the complex. Decreased turbidity will favor primary production, but may also allow increased predation by sight-feeding consumers. In general, top consumers such as large fish, birds, and seals may benefit in this respect at the expense of lower trophic levels.

The Stikine delta is currently expanding at a relatively rapid rate; significant decreases in its sediment budget can slow or reverse this trend (Beak 1981). The paucity of long-term records of Stikine River sediment loads makes predictions of estuarine decreases tenuous. Early estimates ranged between 15 and 60 percent (Beak 1981); recent calculations indicate a 30 percent long-term decrease in sediment may occur (Jones 1983).

Redistribution of sediment and a decrease in number of channels have been predicted (Beak 1982; Jones 1983). Interruption of discharge to the North Arm of the Stikine River would definitely affect bird use of the region (see Part II of this report), and could lead to significant changes in system components ranging from primary producers to top consumers. Additional major redistributions that profoundly alter delta morphology over the long-term are quite possible, but unpredictable.

A decrease in number of channels on the delta would tend to decrease drainage. Because _Carex lyngbyaei_ is favored by well-drained conditions (Kistritz and Yesaki 1979; Moody 1978), this dominant species could experience a decrease in areal coverage. Effects could extend to amphipods, ducks and geese, consumers strongly associated with C. lyngbyaei Heglund and Rosenberg (1984). Sedimentation in side channels and sloughs would allow wetlands to be colonized by species such as willow and alder if not precluded by salt water intrusion. Although detrimental to wetland-dependent fauna, such a change would increase forage for moose (Boertje and Young 1982), thus providing a short-term (5-10 years) benefit. Over the long-term (20+ years), succession would tend towards cottonwood, hemlock and spruce.

Nutrients

Nutrients trapped behind dams are obviously unavailable to deltas and estuaries. Direct effects occur via food webs and are manifest as decreased production.

Riparian systems below dams export nutrients to the estuary. Should these wetland systems be sparse, functionally-impaired or totally replaced by project impacts, the delta/estuarine systems will suffer. McCormick (1978) asked colleagues to estimate the proportion of wetlands that can be removed without significant functional impairment of the estuarine system; they immediately sought refuge in the lack of comprehensive data. When pressed for an answer, the respondents replied uniformly: The failure of an estuarine system may be caused by wetland losses between 10 and 80 percent; however, any loss of wetland area will be reflected by a proportionately similar loss in estuarine resource production (emphasis added).

The High Aswan Dam on the Nile River provides a classic example of a starved estuarine system. The project affected plankton blooms and led to a 27-fold decrease in sardine landings in two years; shellfish landings also dropped dramatically (Aleem 1972). Similar types of effects have been noted in other large systems (Hassan 1975; Jassby 1976).

Earlier sections of this review have indicated that Stikine riparian ecosystems will decrease in abundance and perhaps vigor. Because of the preliminary nature of existing information, quantification of losses has not been attempted. However, the quantity and quality of nutrients exported to the estuary will definitely change. The significance of these changes to the delta/estuarine complex can only be evaluated after adequate quantitative, seasonal data are available.

Organic Matter

The relative amount of organic matter provided by riverine, delta marsh, and marine sources vary for any given system; riverine sources tend to dominate in the Northwest Pacific (Naiman and Sibert 1979). For example, the Fraser River's input of total organic carbon may exceed the estuarine contribution by at least 10 times (Kistritz 1978).

Direct losses of imported organic matter will result from material trapped behind dams. Indirect losses accrue due to impaired functioning of riparian systems and delta marshes. The role of marshes may be highly significant. Kistritz and Yesaki (1979) estimated 66 percent of the above ground biomass of *Carex lyngbyaei* enters the detritus pool. Of that amount, roughly 66 percent is exported; the remainder is buried. The buried fraction is not lost to the ecosystem since it is almost completely decomposed. The authors concluded that (1) the delayed release may be an important mechanism in regulating energy flow in adjacent ecosystems, and (2) release of DOM by *C. lyngbyaei* may be a critical aspect of the estuarine food web.

Relevant studies of estuarine effects caused by dam-induced, organic-matter losses were not encountered; studies of the Stikine system are also lacking.

Temperature

Water temperature changes due to impoundment tend to dissipate along the river continuum; only in extreme cases could measurable temperature changes in water persist to the estuary.

As discussed earlier, ice conditions near the Stikine delta are variable and unpredictable. Should ice-out be accelerated by some means, resultant warming of soils and standing water would enhance growth of biota. The converse is also true.

CONCLUSIONS AND RECOMMENDATIONS

A dam can cause profound structural and functional changes in downstream ecosystems, including estuaries. Should hydroelectric power be developed on the Stikine River, measureable effects will occur. This overview has shown that key alterations involve water flows. Specifically, as flooding magnitudes, frequencies and durations are decreased, spatial and temporal heterogeneity is lost. Authorities agree that wetland losses will be reflected by proportionately similar losses in estuarine production. Therefore, if large-scale, long-term, maximum biological productivity is the ultimate objective, riparian and estuarine ecosystems must not atrophy.

An awesome, unfinished task of the Stikine River hydroelectric development project is quantification of impacts so their significance can be put in perspective. A necessary step in accomplishing such a goal is delineation of the structure of ecosystems, i.e. an accurate description of components. Numerous studies have initiated substantial progress toward this objective: (1) sediment budgets, (2) hydrology regimes, (3) phenology and enumeration of fish, mammals, and birds and (4) delineation of habitat uses/habitat losses by salmonids, eulachon, moose, other mammals, and birds. However, this overview has identified information gaps in several critical areas: (1) nutrient budgets, (2) organic matter dynamics, and (3) estuarine productivity - plankton, benthic infauna, shellfish and fish.

An additional, prominent void exists because most study results have been examined with little regard to their importance in maintaining ecosystem functions. Moreover, there is no indication that entities involved in the project intend to link existing and future site-specific information, or place components in perspective, by adopting an ecosystem approach to project evaluation. Although such an undertaking is formidable, the benefits justify the effort. The systems approach can (1) guide investigators toward pertinent studies, (2) establish a framework for assembling eclectic information, (3) elucidate unexpected results of chains of effects, (4) provide a mechanism for judging relative importance of predicted effects, and (5) properly focus attention toward ultimate questions such as: Will existing ecosystem components (e.g. species of fish or birds) be replaced or lost? Will the ecosystem function with altered components? Will productivity of systems be significantly decreased? Considerations of, and answers to, such questions will greatly aid decision makers of the Stikine River hydroelectric project.

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