ECOLOGICAL INTERACTIONS IN THE FLOODED LITTORAL ZONE OF RESERVOIRS: THE IMPORTANCE AND ROLE OF SUBMERGED TERRESTRIAL VEGETATION WITH SPECIAL REFERENCE TO FISH, FISH HABITAT AND FISHERIES IN THE NECHAKO RESERVOIR OF BRITISH COLUMBIA, CANADA

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PREFACE

Executives and other readers short on time, after scanning the title, reflecting on the photograph below, and reviewing the Table of Contents, may wish to turn directly to the conclusions which provide a brief synopsis of major points emerging from the various sections. We would hope that they might then be enticed to delve more fully into areas of special interest in this review.

Photograph of the Ootsa Depression of the Nechako Reservoir, 20 September 1994, showing a small part of the mainly coniferous flooded forest (over 200 km^2 in all) resulting from its 40.8 m increase in water level. From a slide kindly loaned by Dr. G.F. Hartman.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

This report results from a request by the Skeena Region of the British Columbia Ministry of Environment, Lands and Parks (Fish and Wildlife) to conduct a scientific literature review of the role of submerged trees to fish in reservoirs with recommendations for future research, inventory, fisheries mitigation options, and critical habitat protection issues. In our review we look broadly at ecological interactions in the flooded littoral zone of reservoirs and then relate this perspective to understanding the potential importance as well as problems associated with terrestrial vegetation which may be left or removed from the zone of fluctuation and nearby regions. The focus is first directed to fish habitat, food supply and abundance in impoundments with and without clearing, before turning to recreational and other resource uses of reservoirs. Relevant reservoir studies are reviewed mainly from North America and Scandinavia, before considering in more detail several in British Columbia including those on the Nechako Reservoir itself. Finally, general conclusions are made on the effects of littoral zone clearing in reservoirs along with recommendations for further research and management options specifically for the Nechako Reservoir.

There is a long history of concern, comment and speculation regarding effects of impoundment on the littoral zone of reservoirs, often cloaked in dogma or misunderstanding, but with surprisingly little direct research on the problems, particularly of an experimental nature. In the 1930s fishery biologists studying U.S. reservoirs in Ohio already were suggesting that trees or stumps should be left in impoundments to provide fish habitat (Wickliff and Roach 1937) and planting of various types of vegetation resistant to fluctuating water level was recommended to help stabilize drawdown zones (Weyer 1940). By the early 1940s the short-term “trophic upsurge response” dogma following impoundment was thoroughly in place (Ellis 1942), as were many of the ideas for amelioration of the negative effects of impoundment on fish and fisheries. These included construction of lateral shallows with more constant water level, use of littoral shelters, planting in the drawdown zone, and nutrient enrichment in local areas. Many reappear every decade or so as novel inspirations. As early as the 1960s the effect of standing flooded timber in reservoirs on their productivity and sport fish harvest was listed as one of ten management investigation deficiencies in the review of Jenkins (1961), and he had not changed his opinion nearly ten years later (Jenkins 1970). In our opinion it still probably retains its place there.

The lack of research on the role of standing flooded vegetation in reservoirs up to the mid 1960s is well illustrated by the fact that only seven of the 1210 references reviewed by Jenkins (1965) seem relevant to this topic. Furthermore in reviewing the impact of impoundment on the inland waters of North America, Neel (1963) surprisingly makes no mention of the role of flooded vegetation, nor does Larkin (1972) in his comments specifically on the Nechako Reservoir.

From the mid 1950s and especially throughout the 1960s there was a broad series of excellent studies on ecological effects of impoundment in Sweden, well reviewed by Lindström (1973). Most Swedish reservoirs had to be completely cleared in the drawdown zone to permit use of traditional shore-seine commercial fisheries even though the potential importance of such vegetation was recognized (Lindström 1973). Furthermore Swedish fishery biologists have extensively tested several means of reducing negative impacts of reservoir clearing and fluctuation in the littoral zone (Fürst 1965, Milbrink and Holmgren 1981). In Russia benthic researchers recognized that submerged forests after impoundment served as a substantial reserve for increasing the food base of fish (Poddubnyy and Fortunatov 1961). Nevertheless this did not prevent the extensive clearing of a massive reservoir on the Angara River (outlet of Lake Baikal, Siberia) at Bratsk.

By the mid 1970s the widespread use of computer simulation modeling had gained application for predicting the effects of impoundment, for example on the La Grande River basin of James Bay in northeastern Canada, a sub-model was developed to assess vegetation and shoreline environmental effects (Walters 1975). In his assessment of the impact of hydroelectric impoundments, Efford (1975) notes that there was no prior clearing of trees before flooding of the upper Nechako system, though some very limited underwater cutting of merchantable timber was in progress by then.

Throughout the 1980s there have been many studies examining the importance of flooded terrestrial vegetation in reservoirs with recommendations for reservoir clearing. These include a large study for Ontario Hydro (Anonymous 1981) by Acres Consulting Services Limited. Of the 92 case histories of reservoir clearing practices reviewed, 80 were in Canada and 12 in the United States. Eleven of the Canadian case histories were for reservoirs in British Columbia with another one (Lake Koocanusa) partly so. The B.C. set are surely not representative of the many in the province and Nechako is not included. Four of the reservoirs received complete clearing (Daisy in 1957, Buttle in 1958, Arrow in 1959 and Revelstoke in 1983). Four were partially or selectively cleared (Lower Campbell in 1949, Duncan in 1967, Williston in 1967 and Kinbasket in 1972), and three were not cleared (Hayward formed in 1930, Carpenter in 1960 and Elliot in 1971).

Ploskey (1981) has investigated factors affecting fish production and fishing quality in new reservoirs and has provided a set of recommendations on timber clearing and basin preparation. Furthermore he has assembled a review of impacts of terrestrial vegetation flooding and pre-impoundment clearing in the United States and Canada for the Food and Agricultural Organization of the United Nations (Ploskey 1985); see also Kiell (1982) as well as Laufle and Cassidy (1988).

In Brazilian tropical rivers there has been dramatic loss of fish diversity after impoundment (Northcote *et al.* 1985) and interest in the effects of massive flooding by river impoundment of rain forest there is now developing (Tundisi *et al.* 1993), with a large international seminar on the subject held in Rio de Janeiro in April 1996 (Northcote 1996a).

Again surprisingly, none of the chapters in the book covering ecological perspectives of reservoir limnology (Thornton *et al.* 1990) deals in any significant way with the role of flooded vegetation. Nevertheless the long-term role of century old fallen trees in lakes is at last being recognized and studied (Ridgway 1996).

Here in British Columbia almost at the start of a province-wide survey of its limnological resources in 1949, Dr. Peter Larkin, then Chief Fisheries Biologist of the B.C. Game Department, became embroiled in several major studies of impoundment impacts resulting from proposed hydroelectric developments. The first was on a large tributary to Kootenay Lake vital to its trophy Gerrard rainbow trout (*Oncorhynchus mykiss*) fishery, but no mention was made of flooded vegetation in his review of potential effects (Larkin 1951). The second on the massive impoundment proposed for the Nechako River system (Lyons and Larkin 1952) forms the focus of the present review and will be dealt with in detail later. Lyons and Larkin's main concern expressed in 1952 was the effect of flooding trees on fishability and the subsequent hazards to navigation. The third, dealing with impoundments on the Campbell River system (McMynn and Larkin 1953) also will be discussed in detail later, but again major concerns regarding flooded vegetation revolved around recreational fishability, navigation difficulties and aesthetics. They do comment regarding the flooding of Lower Campbell Lake without appreciable forest clearing, noting that "It is hardly surprising that one would anticipate that aquatic life would be sparse on a stump-studded, alternately wet and dry, recently flooded floor of a coniferous forest." Surprises do occur in limnology, and as we shall see later this may well be one of them!

By the late 1950s in British Columbia interest in the impacts of hydroelectric development on commercial and recreational fisheries was drawn together in a special symposium on fish-power problems (Larkin 1958). Of the ten papers presented on the subject, two might have been expected to consider effects of flooding vegetation. That by Rawson (1958) does not mention the subject. That by Vernon (1958) seems to summarize provincial thinking of the time in the following statement: "Most of B.C. is heavily forested, and when lake levels are raised, large areas of trees may be flooded and killed. Angling is rendered difficult or impossible among standing trees and floating wood debris. The hazards of boating are greatly increased by scattered floating wood and large accumulations of debris in sheltered bays. In addition to the physical effects on angling from boats there is a general lowering of aesthetic and recreational values. During recent years in B.C. the margins of some lakes have been cleared of trees and debris before water levels have been raised. " This viewpoint carried on through a number of other reports on potential impoundment effects - that on the Peace River (Withler 1959), on the Arrow Lakes system (Anonymous 1965a,b) and on the Duncan River tributary to Kootenay Lake (Anonymous 1965c,d). Even the recent review of hydroelectric development impacts on inland fisheries resources in British Columbia (Hirst 1991) makes no mention about flooded timber in its section on habitat quality in reservoirs.

Of course reservoir origin has a profound effect on conditions that later develop within any impoundment. Damming of a river system with few or no mainstem lakes, such as occurred in the Parsnip-Finlay complex forming Williston Reservoir, has very different consequences to those experienced in the damming of the large lakes and rivers complex of the Tweedsmuir Park (Nechako Reservoir) area. In the former the aquatic biota have evolved for life in flowing water and may not adapt easily to a lotic reservoir environment. For example, the Piracicaba River in Brazil lost 53 of its 81 (65.4%) species of fish after impoundment (Northcote *et al.* 1985). Although lacustrine biota also suffer many effects of impoundment, these may not be so severe as those subjected on riverine communities. River dams also would often inundate a greater area of terrestrial vegetation than would be the case for a lake that was raised by a similar height. Shoreline sinuosity should be higher in a dammed river valley (evident by the dendritic shape) than in a dammed lake.

In preparing this review we have used personal lecture material (TGN), references and files as well as those provided by the Skeena Region staff of the Ministry of Environment, Lands and Parks. Relevant references were selected from the following abstracting journals: (1) Applied Ecology Abstracts, (2) Aquatic Biology Abstracts, (3) Aquatic Sciences and Fisheries Abstracts, and (4) Sport Fisheries / Fisheries Review. In addition, subject indices and/or titles were searched in the Journal of the Fisheries Research Board of Canada / Canadian Journal of Fisheries and Aquatic Sciences, in the Transactions of the American Fisheries Society, in the North American Journal of Fisheries Management, and in Lake and Reservoir Management.

2.0 ECOLOGICAL INTERACTIONS IN FLOODED LITTORAL ZONES

The greatest, most severe and long-term effects of impoundment are nearly always expressed on the edges of lakes and rivers that are flooded for various human purposes such as hydroelectric generation, agricultural irrigation storage and domestic or industrial water supplies. These effects are multiple, complex, change markedly over time, and sometimes undergo complete reversals. But as Wootton *et al.* (1996) show so effectively for predicting impacts of disturbance on river food webs, consideration has to be given to the interaction of multiple causal factors.

The littoral zone of any standing body of water theoretically should be its most productive region. It is here where the two layers of highest productivity, the water surface or near surface layer, and the bottom or near bottom layer, overlap. It is also here where the greatest habitat complexity and diversity occurs providing a broad range of differing microhabitats for exploitation of primary producers whether they be attached algae (periphyton), planktonic algae (phytoplankton), or rooted and floating larger plants (macrophytes). Wetzel (1983) devotes two chapters in his basic text on limnology to the importance of the littoral zone and its communities. And not surprisingly it is also often in the littoral zone where the greatest abundance and diversity of zooplankters, benthic invertebrates and fishes are found.

But most reservoirs, especially those used for hydroelectric generation, subject this vital zone to severe and abnormal conditions which can greatly lower its intrinsic high productive capacity. First of all the annual range in water level fluctuation is generally increased greatly so that drawdown changes of 10 to 20 m are by no means uncommon, exposing large areas of littoral zone to desiccation, severe temperature fluctuations, and in northern regions to severe erosion due to ice scouring. Then the seasonal timing of high and low water is usually altered in major ways so that the whole littoral community must either shift its key biological processes greatly or face elimination - too often for some members it may be the latter. Whether or not vegetation in the zone of fluctuation is cleared before impoundment, there will be much greater erosion of fine materials, be they inorganics or organics, from this zone after impoundment. Retention of rooted woody vegetation in the drawdown zone acts to slow this loss by its subsurface soil binding, by its above bottom breakup of erosive wave action, and by its precipitation of colloidal clay particles (Fig. 1). While inundated, woody vegetation also provides a much greater surface area for periphyton and invertebrate attachment than would occur on the bottom if it was removed. Furthermore it can provide refuge habitat for young fishes, lowering their predation rates (Werner and Hall 1988; Osenberg and Mittelbach 1989), as well as providing feeding and spawning habitat for older age classes of at least some species of fishes, as will be discussed later.

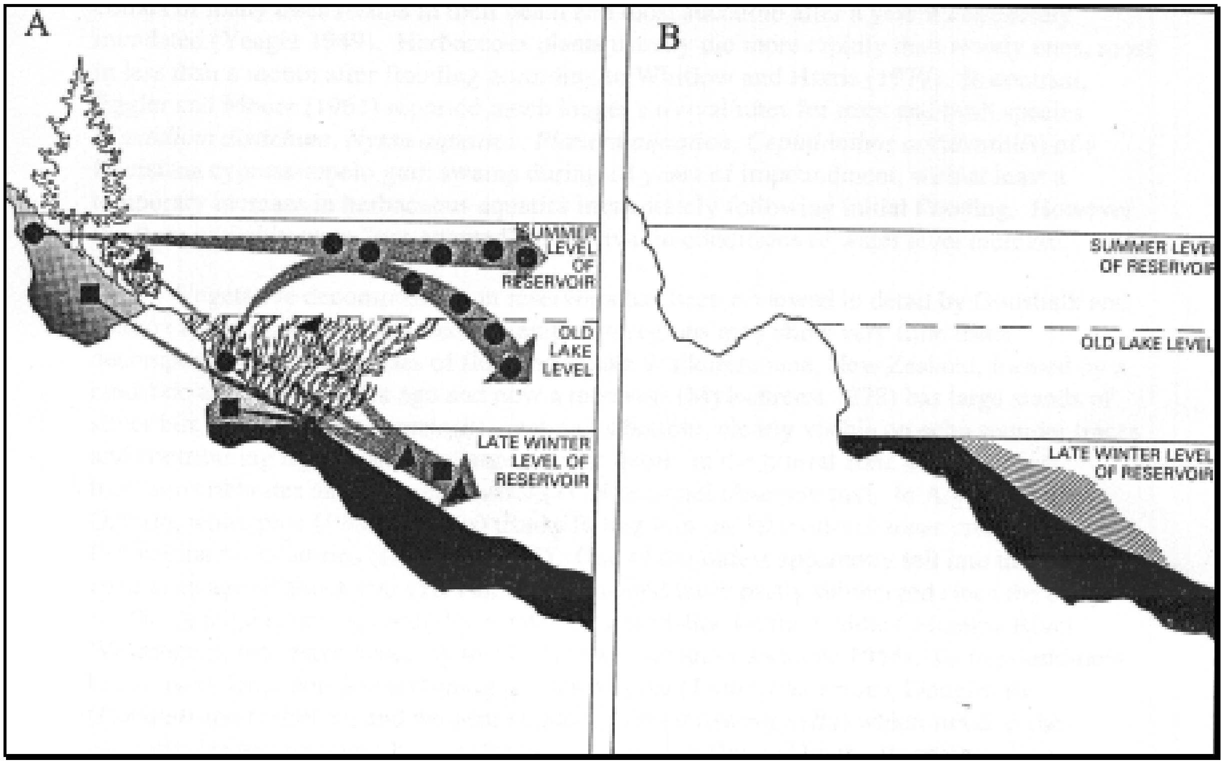


Figure 1. Diagrammatic summary of ecological events occurring in the newly flooded (A) and later (B) shoreline of a reservoir (adapted and modified from Lindström 1973). A: nutrients (●) from newly flooded land and former littoral bottom of a lake are transported out into the open water of the reservoir; soil (■) from newly flooded land and lake littoral bottom is transported downwards with plant debris (▲) from the flooded land and former littoral region. B: eventually most of the organic material in the drawdown zone of the reservoir is lost, with disastrous effects on the littoral flora and fauna; clearing of terrestrial vegetation in the drawdown zone speeds up this process.

3.0 VEGETATION DEATH, DECOMPOSITION AND WATER QUALITY

Short-term seasonal flooding will kill many species of trees in the upper littoral zone of reservoirs (Baxter 1985, Godshalk and Barko 1985) though there are some tolerant tree species, for example willows (*Salix* spp.) and some shrubs that can survive partial inundation (Harris 1975). Above the new high water level, forest vegetation may eventually be killed by erosive bank undercutting (Grelsson 1981), particularly in permafrost regions (Newbury and McCullough 1984). Lowering of water levels in late winter after formation of a heavy ice cover can break and kill large trees (Bollulo 1980). Even permanent flooding only to root collars of many trees results in their death and most succumb after a year if completely inundated (Yeager 1949). Herbaceous plants usually die more rapidly than woody ones, most in less than a month after flooding according to Whitlow and Harris (1979). In contrast, Eggler and Moore (1961) reported much longer survival rates for trees and bush species (*Taxodium distichum*, *Nyssa aquatica*, *Planera aquatica*, *Cephilanthus occidentalis*) of a Louisiana cypress-tupelo gum swamp during 18 years of impoundment, with at least a temporary increase in herbaceous aquatics immediately following initial flooding. However the flora probably were “pre-adapted” to survival in conditions of water level increase.

Vegetative decomposition in reservoirs has been reviewed in detail by Godshalk and Barko (1985). Large woody trees in temperate regions may show very little trunk decomposition after centuries of flooding. Lake Waikaremoana, New Zealand, formed by a landslide about 2000 years ago and now a reservoir (Mylechreest 1978) has large stands of silver birch (*Nothofagus menziesii*) erect on its bottom, clearly visible on echo sounder traces and contributing significantly to large organic debris in the littoral zone as habitat for macroinvertebrates and salmonid fishes (TGN personal observations). In Algonquin Park, Ontario, white pine (*Pinus strobus*) trunks falling into the lake littoral zones create important fish habitat for centuries (Ridgway 1996). One of the oldest apparently fell into the littoral zone at an age of about 400 years and has remained there partly submerged since the early 1500s. A large reservoir naturally created by a landslide on the middle Columbia River, Washington, may have lasted up to 1775 (Lawrence and Lawrence 1958). Its impoundment killed many large conifers including ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga taxifolia*), and western hemlock (*Tsuga heterophylla*) which stood in the naturally drained reservoir bottom for centuries until reflooded by the Bonneville Dam impoundment. Conifers flooded by reservoir formation in high latitudes can last for decades with little change (Van Coille *et al.* 1983). Balsam poplar logs in an Albertan cold water beaver pond have a half life of about 57 years and a 95 % life of about 246 years (Hodkinson 1975). Webster and Simmons (1978) give breakdown rates for a variety of eastern North America trees and shrubs.

Leaves, needles and other soft parts of trees are decomposed much more quickly, as are shrubs, brush and non-woody vegetation (see Tables 1, 2). Fir and hemlock needles lost 80 to 90 % of their initial dry weight after one year of inundation in Findley Lake, Washington (Rau 1978). Conifer needle litter decomposed completely in just over a year in a northern Manitoba reservoir (Crawford and Rosenberg 1984), with the initial loss primarily a result of leaching and microbial conditioning, and the later mainly a result of macroinvertebrate feeding (especially by chironomid larvae). The importance of microflora in cellulose decomposition in reservoirs was noted by Swedish workers in the early 1960s (Overgaard-Nielsen 1962, Grimås 1964), but has been studied intensively elsewhere more recently (Godshalk and Barko 1985).

Table 1. Aquatic decomposition rates and persistence time of various vegetation types. Adapted from Godshalk and Barko (1985).

Vegetation tissue type	**Annual % weight loss**	**Mean persistence time (days)**
Submersed, floating	94.6	87
Deciduous leaves	90.3	108
Conifer needles	83.4	141
Emergent, marsh	67.7	224
Wood	4.6	5,332

Table 2. Decay parameters for various vegetation types in a cold water beaver pond, Alberta. Adapted from Hodkinson (1975).

Vegetation type	**Half life (years)**	**95% life (years)**
Willow (*Salix* spp.)[a]	0.71	3.05
Grass (*Deschampsia caspitosa*)[a]	1.04	4.49
Rush (*Juncus tracyi*)[a]	1.70	7.33
Pine needles (*Pinus contorta*)	3.22	13.92
Spruce bark (*Picea glauca*)	5.75	24.90

[a] leaves and stems.

Inundation of trees, brush, shrubs and other terrestrial vegetation in the flooded zone of reservoirs can result in rapid, dramatic and in part detrimental effects on water quality conditions (Ploskey 1985, Godshalk and Barko 1985). These are not reviewed in detail here (see especially Ploskey 1985, Godshalk and Barko 1985 for extensive coverage), but some general relevant features are summarized in Fig. 2. Because of the great variation regionally and with specific conditions of impoundment, no absolute time scales are given, but most of the changes outlined can occur in less than a decade, many within a year or two, and some in a matter of weeks to days.

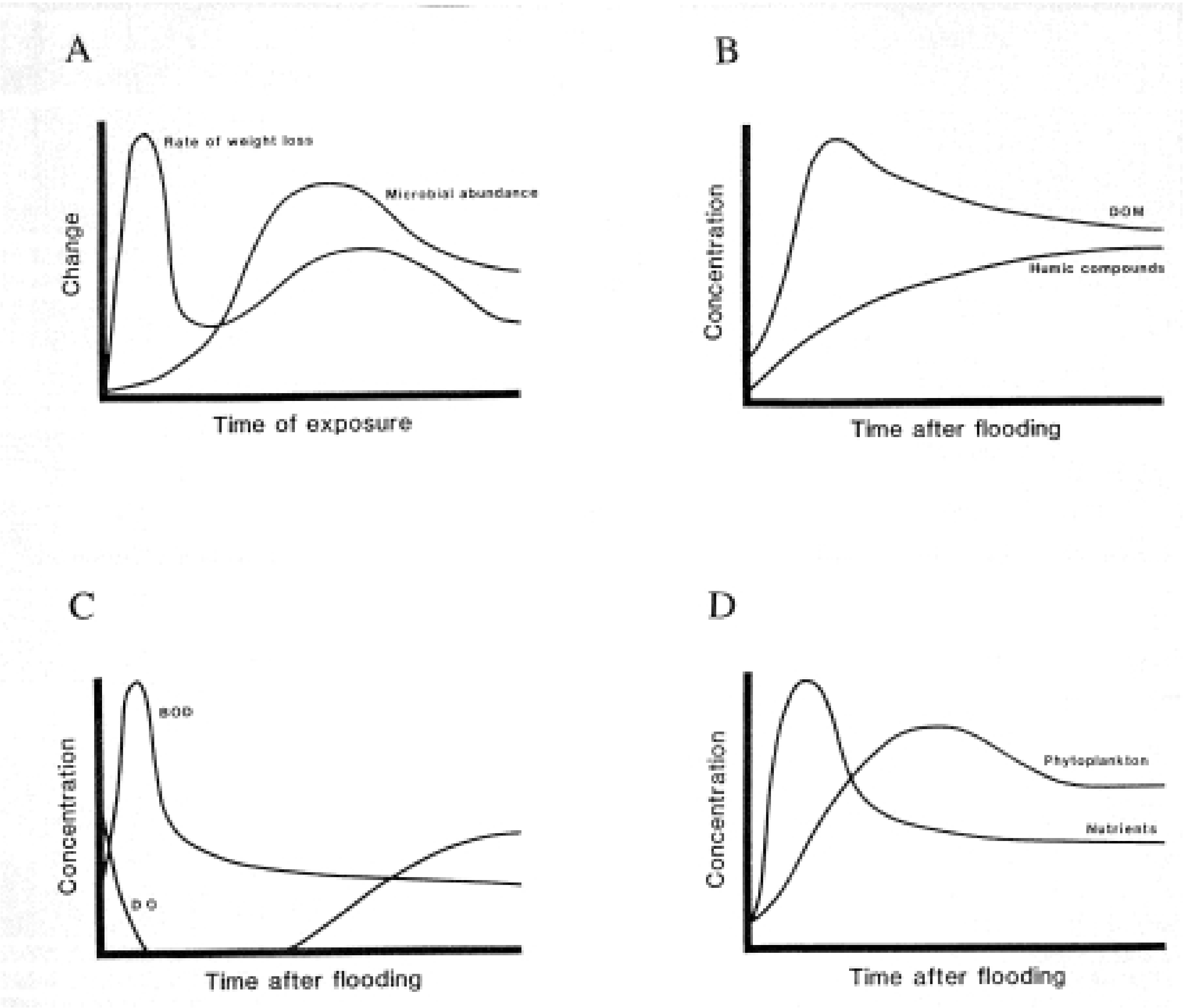


Figure 2. A generalized synthesis of major water quality and related changes following flooding of littoral soils and vegetation in a reservoir. Adapted from Godshalk and Barko (1985).

A: Detritus weight loss first from abiotic leaching and later (second smaller peak) after maximum in microbial abundance and decomposition.

B: Concentration changes in total dissolved organic matter (DOM) and the fraction from humic compounds. DOM peaks early because of leaching and declines as it is mobilized; later it is dominated by large, refractory humic molecules.

C: Concentration changes in dissolved oxygen (DO) and its bacterial consumption by decomposition as biological oxygen demand (BOD); consumption peaks rapidly due to leached labile DOM (see B) and DO is depleted.

D: Concentration changes in major nutrients released during decomposition and the responses of phytoplankton to available nutrients; nutrient concentration peaks early from leaching of newly flooded soils and terrestrial vegetation.

Probably all those depicted would have occurred in Nechako Reservoir after impoundment, although it is unlikely that dissolved oxygen in most areas would have decreased to zero (see Fig. 2C), and the concentration peaks as well as their timing may not have closely followed that suggested. Nevertheless in enclosed bays of a large northern B.C. lake (Babine), severe oxygen depletion (<2 mg/L) occurred very quickly in log storage areas (Power 1988, Power and Northcote 1991) and biological oxygen demand (BOD) of vegetation leachates in early stages of timber submergence could be high (Atkinson 1971, Servizi *et al.* 1971). Furthermore highly toxic compounds (terpines, tropolones, lignans and others) can be released from flooded and decomposing or stored vegetation in B.C. and Alaskan waters, causing heavy mortality in aquatic invertebrates and fish (Pease 1974, Peters *et al.* 1976, Buchanan *et al.* 1976). In contrast, Ball *et al.* (1975) claim that water quality effects from decaying wood in reservoirs cannot be detected after three months from inundation.

4.0 LITTORAL COMMUNITY AND FOOD WEB IMPACTS

4.1. Aquatic plants

Littoral zone flooding affects all three sources of primary production in reservoirs: periphyton, macrophytes and phytoplankton (Wetzel 1983, Baxter 1985, Kimmel and Groeger 1986). Where water level increases and fluctuations are minor there can be rapid development of dense periphyton growth, especially on the flooded terrestrial vegetation (Benson and Cowell 1967, Claflin 1968, Baxter and Glaude 1980; see also Fig. 3). Flooding of vegetation and underlying soil often brings about a short-term nutrient increase (Fig. 2). Periphyton in some inland standing waters can be the major contributor to primary production (Wetzel 1983). Flooded trees and logs in tropical reservoirs may develop very high periphyton cell densities (Obeng-Asamoa *et al.* 1980, Nwankwo *et al.* 1994).

Macrophyte growth in reservoirs subject to much fluctuation in water level usually is restricted to the lowermost drawdown point or below, as was evident in Buttle Reservoir (Vancouver Island, B.C.) in October 1996 (TGN personal observations). Nevertheless in those with small level fluctuations, the inundated trees and brush can enhance macrophyte colonization by the protection provided from strong wave action and by reduced erosion of organic sediments (Nichols 1974). On the littoral bottom of Douglas Lake, Michigan, 30 year old brush shelters facilitated establishment of rooted aquatic vegetation (Thomas and Bromley 1968), as did stumps, brush and fallen trees in Buckeye Lake, Ohio (Judd and Taube 1973). Partly submerged trees in Kariba Reservoir in Central Africa were important for anchoring mats of *Salvinia auriculata* (McLachlan 1969).

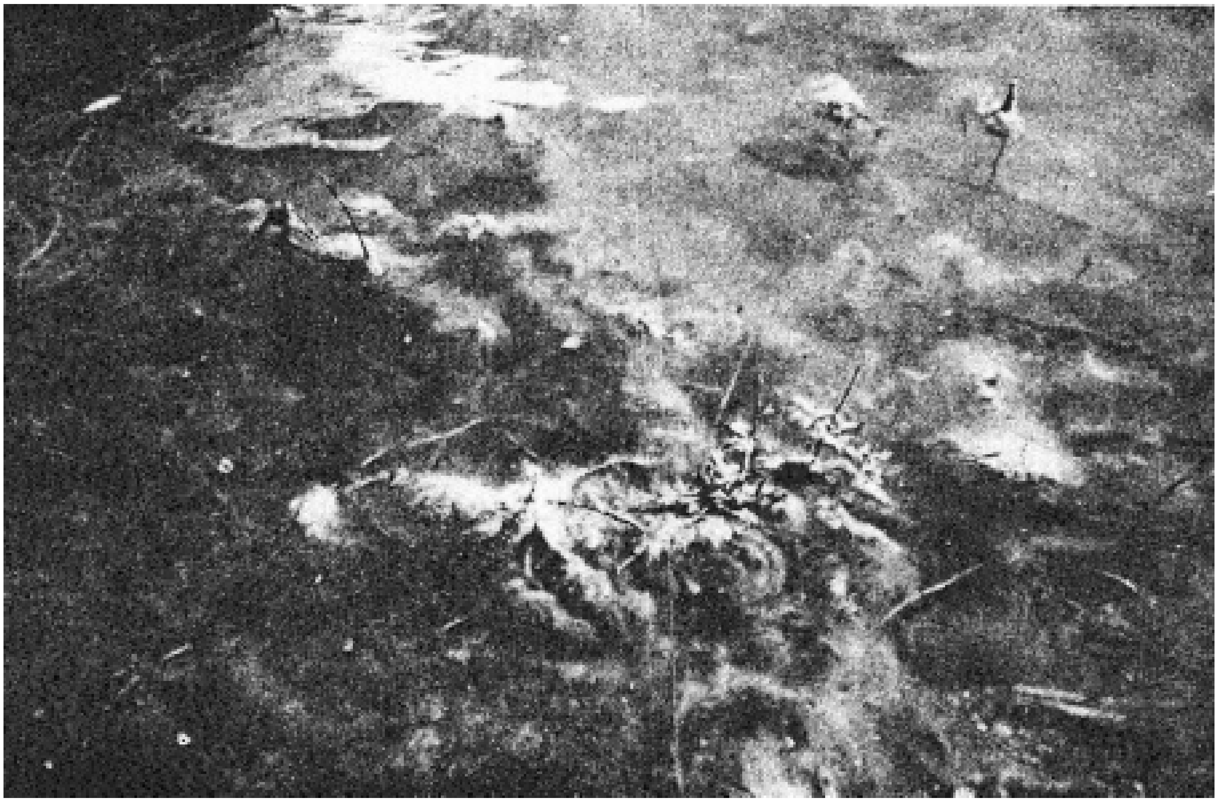
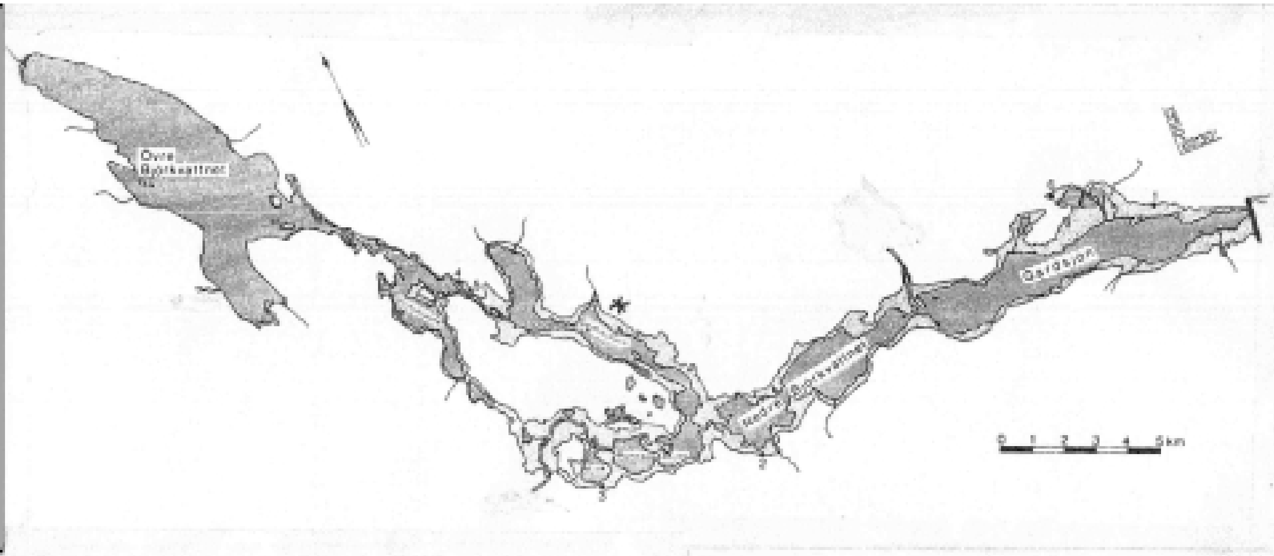


Figure 3. Dense periphyton growth on flooded terrestrial vegetation in the littoral zone of impounded Southern Indian Lake, northern Manitoba. From Baxter and Glaude (1980).

Undoubtedly the most detailed and long-term study on macrophytes in and adjacent to the drawdown zone of a reservoir has been that on the Lappish string of lakes in northern Sweden impounded in 1961 to form Gardiken Reservoir (Wassén 1965). Some 304 species of higher plants and 98 species of mosses were recorded from the shoreline areas of the system (Wassén 1966). The higher plants included two species of *Deschampsia*, a grass genus. Dr. Wassén found a species of the same genus of grass in the late 1960s along the shoreline of Dry Lake near Princeton, B.C. in a zone flooded in the spring but exposed for most of the year by a natural fluctuation of over 5 m in lake level. The Dry Lake species had upper roots like coil springs which Dr. Wassén thought might be important to its survival in this zone of severe level fluctuation. Gardiken Reservoir, Sweden has a reversed vertical amplitude (low in the spring and high in late summer to autumn) of 20 m (Fig. 4). Changes in flora and vegetation cover on the shore were correlated with the degree of exposure to wind and wave action, to substrate type, and to seasonal water levels (Nilsson 1978, 1981), with the shore vegetation of this reservoir dominated by short-lived species capable of setting large numbers of seeds that are viable for several years when buried in the soil.



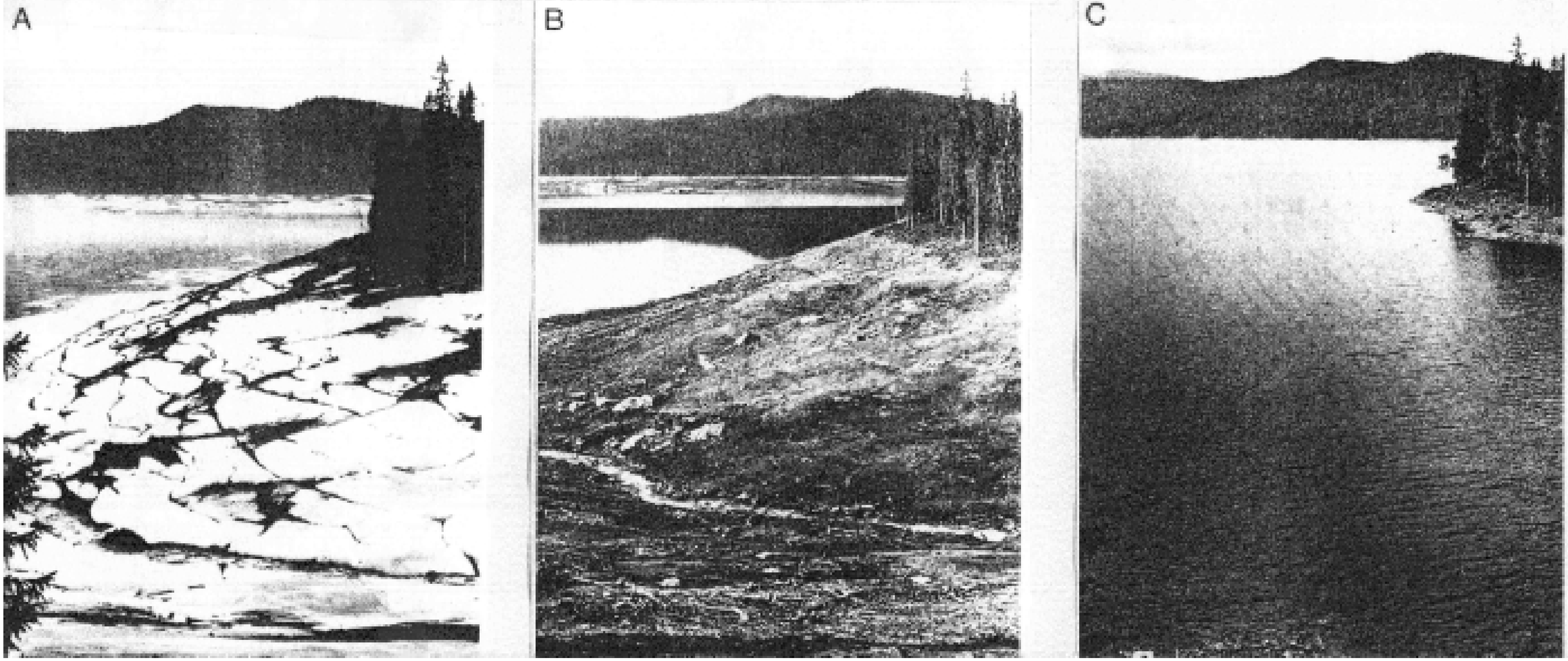


Figure 4. Map (upper) of Gardiken Reservoir system (fine stippling) in northern Sweden (19°50’N, 65°30’W) formed by impoundment of a chain of lakes (dark hatching). * shows approximate photograph (A, B, C) site. A: spring at lowest level, shore ice-covered. B: early summer, still at lowest level, shore exposed. C: late summer, high water level. Adapted from Nilsson (1981).

Old reservoirs become devoid of all permanent aquatic vegetation if their amplitude exceeds 7 m (Nilsson 1979), but in those where summer levels are reasonably constant and overall fluctuations are narrow, the shoreline can attain a relative stability in a couple of decades (Nilsson and Keddy 1988). Seda (1968) discusses the natural development of vegetation around reservoir shorelines, as well as plants suitable for introduction into such regions.

Relationships between flooded vegetation and phytoplankton production in the littoral zone of reservoirs are largely indirect (Ploskey 1985), resulting from the usual nutrient upsurge shortly after impoundment. Phytoplankton densities were 5 to 100 times greater over reservoir margins where soil had not been stripped (Campbell *et al.* 1975), whereas topsoil removal greatly lowered carbon (C), nitrogen (N), and phosphorus (P) nutrient levels and reduced phytoplankton growth potential by over a half.

4.2. Invertebrates and detritus processing

Over 30 years of benthic studies in littoral zones of reservoirs ranging from North America to Europe and Africa support the view that flooded terrestrial vegetation can support a very rich invertebrate fauna. Predictably some of the best early studies come from Sweden, notably those of Grimås (1961, 1962, 1964, 1965a,b) showing that protected bays with trees and shrubs remaining have much higher benthic abundance than do exposed areas which have lost most of the original terrestrial organic matter. Experimental results reported by Gubanova and Vershinin (1965) for Kamskoe Reservoir (then in the U.S.S.R.) using suspended bundles of different tree species (spruce, pine, birch) show that benthic biomass (mainly chironomids) on the tree bundles exceeded that on the nearby bottom by about seven fold. Claflin (1968) also found an abundant macrofauna (again mainly chironomids) on inundated logs and trees of two mainstem Missouri River reservoirs. The chironomid midges grazed on periphyton and pupated there while the adults used the flooded trees as eclosion (hatching) sites. In impounded Lake Kariba, Africa, submerged trees formed an important substrate for benthic fauna which gained access between bark and xylem by the action of two species of wood boring beetles (McLachlan 1970). With multiplate benthos samplers, Aggus (1971) compared summer colonization rates on three different types of flooded littoral zone in the Bever Reservoir in Arkansas: (1) hardwood forest with sparse understory; (2) herbaceous plant cover and; (3) cleared forest with some small hardwood and herbaceous plant regrowth. The colonizing fauna (mainly chironomid larvae with small numbers of other insect larvae, oligochaete worms and crustaceans) were highest in herbaceous plant cover for the first few years after flooding, but the large woody vegetation continued to serve longer as attachment and eclosion sites. Jones and Selgby (1974) as well as Strange *et al.* (1982) also found higher densities of benthos in flooded herbaceous vegetation of U.S. reservoirs. In a Georgia reservoir Benke *et al.* (1984) reported that invertebrate standing stock biomass (per unit surface area) on snags was 20 to 50 times greater than on sandy habitat and 5 to 10 times greater than on mud habitat. Also taxa diversity was greater on snags than on the other two habitat types. Regional differences in macrobenthos standing crops were related to nutrients leached from flooded vegetation in the Southern Indian Lake Reservoir in Manitoba (Wiens and Rosenberg 1984). Coutant (1996) notes that in streams "submerged wood is an important habitat in aquatic systems for growing invertebrates, especially aquatic insects of the family Chironomidae (midges)", and no doubt they also use submerged wood in reservoirs. Further supporting references and discussion of causal factors can be found in Ploskey (1985).

In addition to the enhancement of epibenthic invertebrates via the colonization of flooded terrestrial vegetation by periphyton and other flora associated with "aufwuchs" (a German limnological term for the biotic layer that grows upon a surface), and the nutrients that leach out of vegetation as it gradually decomposes, the large surface area provided by complex vegetative structure must be considered. That surface complexity is positively correlated to associated invertebrate density is well known for submerged macrophytes (Pardue and Nielsen 1979, Cyr and Downing 1988, Hargeby 1990), but these usually die down seasonally whereas many woody terrestrial plants in the flooded zone can provide stable surfaces year-round for decades.

Two other invertebrate groups in the littoral invertebrate community that may be affected by flooding of terrestrial vegetation should be noted: (1) the planktonic or semi-planktonic forms, and (2) the surface dwelling or trapped forms. The first have been well studied by Swedish reservoir biologists (see especially Lindström 1973 and references therein) and more recently reviewed in Ploskey (1985). In the first few years after impoundment large zooplankton populations often develop in areas of flooded herbaceous vegetation or grasses with littoral cladocerans such as *Moina affinis*, *Scapholebris kingi* and *Sida crystallina* as well as rotifers becoming particularly abundant (Wright 1954, June 1974, Aggus 1971, Benson 1968). Flooded littoral areas of Lake Nottely, Georgia, that were seeded with grasses had significantly higher zooplankton abundance than those in barren areas (Strange *et al.* 1982).

There seems to be very little attention given to the invertebrate community associated with the water surface of reservoirs, whether in littoral regions or in pelagic areas. Norlin (1964) conducted one of the few intensive studies, again on two impounded lakes in northern Sweden. Samples taken off shores in a flooded agricultural area covered with conifers showed only small differences in abundance of terrestrial insects on the water surface, probably a result of rapid mixing and drift over the whole reservoir surface. Sinclair (1965) attributed the higher number of terrestrial insects on the surface of Buttle Reservoir on Vancouver Island, compared to Lower Campbell Reservoir nearby, to the greater gathering capacity of the steep shoreline and large size of the Buttle Reservoir.

The role of aquatic invertebrates in processing woody debris has been well studied in stream habitats (see for example Anderson *et al.* 1978, 1984), but similar relationships no doubt operate in reservoir littoral zones at least when flooded. This subject has been considered briefly in the previous section on decomposition of inundated terrestrial vegetation and will not be dealt with further here.

5.0 FISH LITTORAL HABITAT EFFECTS

5.1. Adult spawning habitat

The many species of North American freshwater fishes that can use flooded terrestrial vegetation for spawning are reviewed by Ploskey (1985). Most are warmwater species in the gar (lepiosteids), shad (alosids), minnow (cyprinids), catfish (ictalurids), and bass (centrarchids) groupings. Special attention to effects of hydroelectric development on the reproductive biology of northern fishes such as the lake whitefish (*Coregonus clupeaformis*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*) and walleye (*Stizostedion vitreum*) is given in reviews by Machniak (1975), but generally breeding of these species is not directly affected by flooding of terrestrial vegetation.

An increase and then a decline in young yellow perch in Lake Francis Case Reservoir in South Dakota was attributed to an increase in spawning habitat after initial flooding and then its subsequent deterioration (Gasaway 1970), and a similar response was noted in another South Dakota reservoir for two species of buffalo fish (*Ictiobus*) (Elrod and Hassler 1971). Woody debris was a preferred nesting material for pumpkinseed sunfish (*Lepomis gibbosus*) at the start and close of its breeding season (Colgan and Ealey 1973). Shoreline brush was a consistently preferred spawning habitat for spotted bass (*Micropterus punctulatus*) in the U.S. Bull Shoals Reservoir (Vogele and Rainwater 1975). The reduction in wave action, shoreline erosion and near-shore sedimentation provided by flooded terrestrial vegetation can have beneficial effects on spawning habitat of some freshwater fishes. Increased sedimentation following impoundment of Southern Indian Lake, Manitoba, caused higher overwinter egg mortality of lake whitefish (Fudge and Bodaly 1984). Increased water level fluctuations on shoal and emergent macrophytes used for spawning reduced population abundance of lake whitefish and northern pike in Rainy Lake and Namaken reservoirs (Cohen and Radomski 1993).

5.2. Juvenile rearing habitat

A long series of studies have examined relationships between inundated terrestrial vegetation and early rearing habitat of juvenile freshwater fishes. Those on Lake Oahe, a Missouri River mainstem reservoir, showed high abundance of young-of-the-year fishes in areas of flooded trees and brush in the first few years after impoundment (Walburg 1966, Beckman and Elrod 1971, June 1976). Similar results were suggested for larval shad (*Dorosoma* spp.) in other U.S. reservoirs by Edwards *et al.* (1977) and Van Den Avyle and Petering (1988). Vegetated regions of any type were important nursery areas for several species of warmwater fishes in Florida, perhaps due to the structural complexity that was provided (Conrow *et al.* 1990). Meals and Miranda (1991) show that inundated coves and sloughs yielded the highest abundance of 0+ sunfish (*Lepomis* spp.), crappie (*Poxomis* spp.), and largemouth bass (*Micropterus dolomieui*), whereas lowest numbers were found on mud/sand shores. The finding in Babine Lake, British Columbia (Power and Northcote 1991) that significantly lower food supply was available to juvenile sockeye salmon (*Oncorhynchus nerka*) in areas of fresh-cut conifer logs could have relevance to conditions in recently flooded littoral zones of northern reservoirs.

5.3. Adult feeding habitat

Much of the early work on effects of impoundment on feeding of older age classes of salmonid fishes in flooded littoral zones was done in Sweden (Nilsson 1961, Lindström 1973). More recent reviews, mainly for warmwater fishes, are provided by Ploskey (1985) and by Laufle and Cassidy (1988). Direct observation of feeding behaviour indicates that many fish species take prey directly from flooded terrestrial vegetation, as Baker and Schmitz (1971) showed for two species of shad which used the aufwuchs attached to the submerged surfaces. A number of carefully controlled experimental studies point to the importance of vegetation structural complexity in providing rich feeding sites, as well as giving shelter and protection from ambush predators such as bass and northern pike (Crowder and Cooper 1979, 1982; Savino and Stein 1982, Dionne and Folt 1991, Savino *et al.* 1992, Hayse and Wissing 1996). Clearly more work is needed on this subject for northern reservoirs and their fish communities.

6.0 FISH ABUNDANCE AND FISHERIES

A long series of studies, again mainly in southern North American reservoirs and with warmwater species, have investigated fish abundance in areas of flooded vegetation and made comparisons with cleared areas and those with little or no vegetation before flooding; most but not all have found fish densities to be higher in areas of flooded vegetation (Coke 1968, Cherry and Guthrie 1975, Ruggles and Watt 1975, Moring *et al.* 1982, Durocher *et al.* 1984, Willis and Jones 1986, Negus 1987, Moring *et al.* 1989, Gelwick and Matthews 1990). Other work has compared fish abundance with vegetated and low or non-vegetated sites with similar results (Gullory *et al.* 1979, Chick and McIvor 1994, Randall *et al.* 1996). Removal of vegetation (*Hydrilla verticilla*, *Myriophyllum spicatum* and *Ceratophyllum demersum*) by grass carp (*Cyprinus carpio*) in a Texas reservoir resulted in a decline in abundance of brook silverside (*Labidesthes sicculus*) as a result of competitive interactions, but an increase in inland silverside (*Menidia beryllina*) populations (Bettoli *et al.* 1991).

At least for the first few years after impoundment and often longer, angler use and catch success usually have been higher in reservoir areas with flooded vegetation (providing access is not restricted or made hazardous by floating debris or underwater stumps), compared to cleared areas (Burress 1961, Benson 1968, Gasaway 1970, Davis and Hughes 1971, Jenkins and Morris 1971, Bartholomew 1972, June 1976, King *et al.* 1979, Ploskey 1981, Hanna and Michalski 1982, Timmons and Garrett 1985), but all of these studies were on warmwater species. No detailed data were found for salmonid species. Over doubling the flooded surface area of Spada Lake, Washington, after clearcutting and burning of much of the slash on the new impounded area, did result in an increase in angler yield for rainbow and cutthroat trout (*Oncorhynchus clarki*) from less than 1000 kg/year to nearly 5000 kg/year shortly afterwards, but then harvest declined (Stables *et al.* 1990).

7.0 PRE-IMPOUNDMENT PREPARATION FOR FLOODED AREAS

Pre-impoundment preparation work on an area to be flooded has ranged from virtually none except that necessary for construction of the dam itself (such as that on Stave Lake, British Columbia; see Efford 1975), to almost complete clearing and burning of all surface vegetation as well as grubbing out of roots (as occurred in many Swedish reservoirs to permit commercial shore seining, or at Buttle Lake, British Columbia in attempts to minimize problems in recreational use of a park). Obviously the major purpose for any impoundment and the additional uses that are to occur in it will condition pre-impoundment preparation work. Now for most North American impoundment proposals and in many other areas, whatever the prime purpose for a reservoir, recreational uses must be given full and serious consideration (see Larkin 1972).

A thorough review of this subject for Canada and the United States is given by Ploskey (1985), drawing heavily for Canada on the report of Acres Consulting Services Limited to Ontario Hydro (Anonymous 1981), and for U.S.A. on policies and guidelines used there by the three major reservoir construction agencies - the Tennessee Valley Authority, the U.S. Department of the Interior's Bureau of Reclamation, and the U.S. Army Corps of Engineers. Up to the mid-1980s pre-impoundment preparation of the area to be flooded for most reservoirs in both Canada and the U.S. was developed on strategies for operational needs, for navigation and public safety purposes, for timber harvesting opportunities, for aesthetic needs (at least as far as could be seen from public viewing sites on the dams), and for mosquito control, with fisheries and recreational needs not being given prime consideration except in promotional material. Of course there have been exceptions, but these would probably form a minor percentage of the thousands of reservoirs built in the last half of the 20th century in North America. The blame for this approach should not rest solely on the dam builders! Fisheries recreational and environmental advisors from both governmental and non-governmental agencies or groups often have not been clear on what pre-impoundment preparation work was needed for their purposes, or at times have been either unrealistic or misguided in their demands. In British Columbia, at least throughout the 1950s and 1960s, complete clearing of areas to be flooded was usually requested when in hindsight perhaps that was not environmentally the best option for fisheries or for recreational purposes (assuming that there was no alternative to impoundment). But then there was no solid body of thorough research on the subject based on conditions and species relevant to this region which could be used to formulate good recommendations. Most unfortunately that still is very much the case even today! Certainly forestry interests in the province were not reluctant to firmly put forward a series of priorities to be followed regarding their resource in pre-impoundment preparation plans (Hatton *et al.* 1976). Because of the great variation in site preparation to be expected depending on region and reservoir use, there is little point here in reviewing the specifics; the temporal range of these can be checked in the following references: Wickliff and Roach (1937), Anonymous (1956a,b), Jenkins (1970), Atton (1975), Campbell *et al.* (1975), Anonymous (1981), Kiell (1982), and Ploskey (1985).

8.0 MITIGATORY MEASURES IN FLOODED LITTORAL ZONES

Of the range of actions that could be taken to ameliorate fishery purposes the negative effects of littoral zone flooding, at least four were suggested as early as the 1940s. These included: (1) construction of lateral shallow water areas tributary to the main impoundment where water level could be maintained at a desirable level, (2) installation of floating or sunken shelter habitat, (3) planting of vegetation in the drawdown zone, and (4) addition of specific nutrients and organics to soil and water in specific areas (Weyer 1940, Ellis 1942). Later Jenkins (1961) reviewed the limited success of these and added (5) heavy stocking of indigenous sport and forage fishes, a practice surely followed with varying success in North America and Scandinavia. To these, two others could be added (6) introduction of exotic invertebrates as prey for fish, and (7) selective clearing and/or leaving of patches of terrestrial vegetation, again a practice that has been used since the 1950s. The subject has been discussed briefly in the previous section and extensively reviewed by Ploskey (1985), mainly for southern North American reservoirs and species assemblages. He gave several recommendations to serve fishery interests there, including some which may have relevance to northern B.C. reservoirs:

1. Provide suitable water quality and habitat for principal species that are likely to dominate post-impoundment fisheries;

2. Provide good access for fishermen at a number of equitably distributed sites around new reservoirs;

3. Provide for safe navigation throughout the main body of the reservoir and;

4. Provide protected areas zoned exclusively for recreational angling by leaving uncleared certain coves, embayments, backwaters, or nearshore areas. For a recent example regarding this recommendation see Engel (1987). Laufle and Cassidy (1988) provide a recent discussion of the merits of retaining standing timber in reservoirs for fish (centrarchids and salmonids) albeit primarily for rainbow trout and wildlife habitat.

In a review of 18 reservoirs where selective clearing was carried out in the flooded zone, 11 (61.1%) were judged to be successful, 6 (33.3%) marginally successful, and 1 (5.6%) unsuccessful (Nelson *et al.* 1978). Clearing of standing terrestrial vegetation (usually timber for commercial forestry) has been conducted in some reservoirs (Anonymous 1971, Fowler

1979, Bolullo 1980, Moring *et al.* 1982,1986; Malyshev and Shkundin 1988). Ecological effects of such salvage logging has been evaluated in some Maine reservoirs (Negus 1982, Moring *et al.* 1982, 1986).

Construction of small inlet impoundments has been tested in Lake Kultsjon, Sweden by Grimäs (1965b) and seemed to be effective in preserving a higher biomass, abundance and diversity of littoral bottom fauna important for salmonid fish feeding than was the case in the main lake itself after impoundment.

Creating fish shelters or attractors in flooded littoral zones of reservoirs has been followed with a great range in structural complexity for nearly half a century. Most have been deemed successful but in general their evaluation has not been rigorous. For examples over this period see Parsons (1957), Martin (1957), Wilbur (1978), Sims (1982), Thomas and Wilson (1984), others in Ploskey (1985), Johnson and Lynch (1992), and Rold *et al.* (1996).

Planting flood tolerant vegetation in the drawdown zone, also has a long history (Kimsey 1957, Seda 1968, Thomas and Bromley 1968, Gill 1977, Allen and Klimas 1986), but with little apparent success. Similar results could be expected in northern B.C. due to ice formation and erosion.

Perhaps the most successful results with nutrient addition have been those of Milbrink and Holmgren (1981) in Swedish reservoirs (Fig. 5). Continuous enrichment of a small stream leading into a reservoir bay protected from wind action promoted development of a rich littoral zooplankton fauna that was used by Arctic char (*Salvelinus alpinus*), the latter improving their condition.

Introductions of exotic invertebrates such as *Mysis relicta* have had some success in Scandinavia but not in North America (Northcote 1991). For the most part in North America their introductions have been ecological disasters and should not even be contemplated for the Nechako or other reservoirs. Though some kokanee (*Oncorhynchus nerka*) populations temporarily showed increased growth rates in Kootenay and Okanagan lakes, B.C. these later declined, and in many other North American lakes and reservoirs the responses have been highly negative (see also Martin and Northcote 1991).

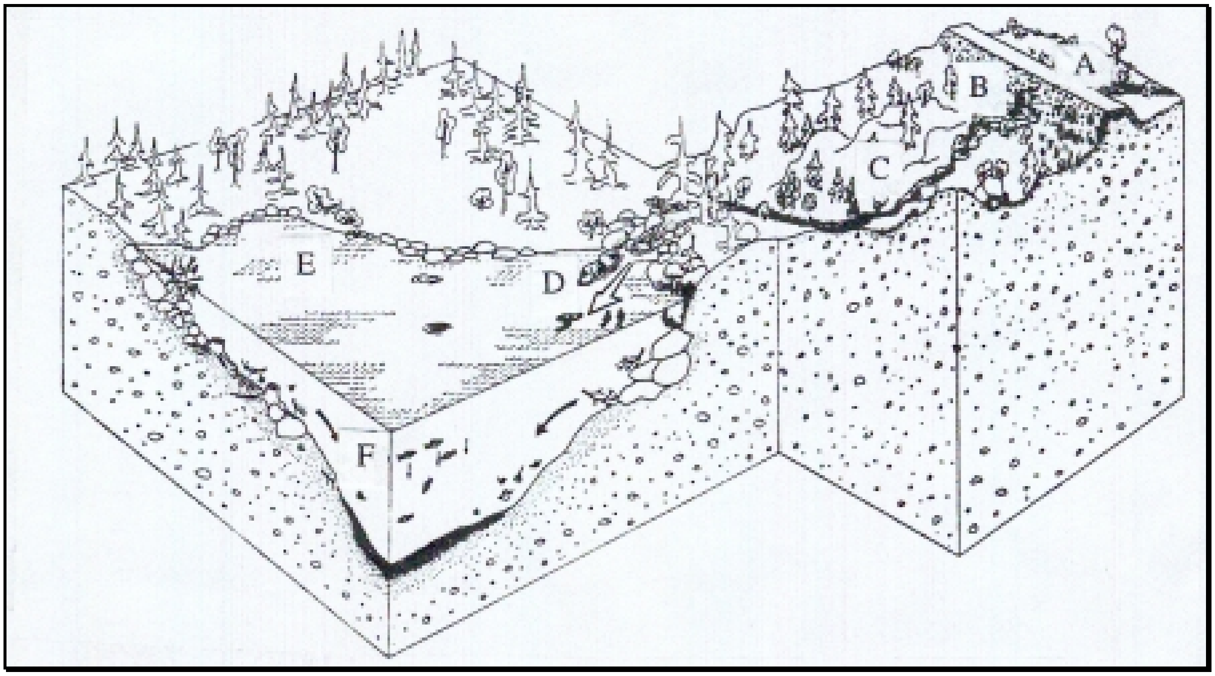


Figure 5. Diagrammatic representation of a sheltered bay along a Swedish reservoir shoreline with an inflowing stream receiving regulated nitrogen and phosphorus addition. A: a road culvert nutrient introduction site; B: a mixing pool immediately downstream; C: a natural barrier to upstream fish migration; D: the stream mouth where brown trout (*Salmo trutta*) concentrate; E: shallow areas in the bay where European grayling (*Thymallus thymallus*) are common; F: deeper areas of the bay inside a row of protecting islands where Arctic char (*Salvelinus alpinus*) thrive. Adapted from Milbrink and Holmgren (1981).

9.0 THE CAMPBELL RIVER IMPOUNDMENTS

One of the first studies in British Columbia directly related to evaluating effects of terrestrial vegetation clearing on land flooded by impoundment was that by Sinclair (1965), who worked on the Campbell River system, Vancouver Island (Fig. 6). Though some aspects of his work were reviewed by Geen (1974), it would be useful here to summarize the relevant findings and to add results of an additional survey conducted in October, 1996.

Lower Campbell Lake was studied briefly before its impoundment (Carl 1937; see McMynn and Larkin 1953, Sinclair 1965) which occurred in 1949 and raised its level 17 m. In the first few years after impoundment its water level fluctuated by as much as 13 m but in the early to mid 1960s this had decreased to about 3.5 m. Most of its flooded area had been logged of old growth timber previously, so only a few large coniferous trees were removed before impoundment and the "second growth" forest (mainly Sitka spruce - *Picea sitchensis* - according to a personal communication to D.C. Sinclair from A.W. Lash) and associated shrubs and minor vegetation were flooded without any clearing. In 1964, Sinclair (1965) noted that the “combined effect of low fluctuation and incomplete clearing resulted in far less damage [than at Buttle Reservoir] to the bottom through the effects of erosion”, and that “much of the shoreline in bays was covered with sand and silt among the stumps and debris”.

Buttle Lake in Strathcona Provincial Park was impounded in 1958 by a dam about 3 km upstream from the upper end of Lower Campbell Reservoir (Fig. 6), raising its level 9 m with level fluctuations as high as 8 m in the first few years after impoundment but reducing to about 5.5 m by the mid 1960s. Because of its park location a very complete clearing of vegetation was required at Buttle Lake. Therefore all trees in the flooded zone, a mature climax forest of Sitka spruce, western hemlock, and western red cedar (*Thuja plicata*) were cut as close as possible to the ground, as were the shrubs and other minor vegetation. All branches and other woody material were burned. Furthermore over most of the area to be flooded on slopes less than 15% and around the mouths of all tributaries, complete grubbing (digging up) and burning of roots, small stumps and other minor vegetation was carried out. Sinclair (1965) noted that “By 1964 the exposed zone of regulation which was thoroughly cleared and grubbed had become little more than a large sterile gravel bar, as a result of wave action and erosion.”

From observations in 1980 and 1996, conditions in the littoral zone of fluctuation in the two reservoirs (Figs. 7-12) apparently had not changed greatly over the 32 years since Sinclair’s study, though in Buttle Lake a few small patches of rooted macrophytes were found near the lower drawdown limit at one location protected from strong wave action (Fig. 11).

Water quality conditions at the two reservoirs and sites within them were similar (Table 3), except for higher brown-stained organics (water colour, Pt units) probably coming from large amounts of finely shredded bark at the protected Buttle Lake site, and the higher concentrations of dissolved copper there as well.

The poorly documented data on benthic invertebrate abundance in the upper littoral zone of Lower Campbell Reservoir, before and after impoundment (Table 4), are too sparse to permit valid comparisons except to note that numbers of chironomid midge larvae apparently decreased between 1951 and 1964. Absence of other faunal groups in 1951 must be a result of inadequate sampling then, as most were found in October 1996 epibenthic sweep sample data to be shown later. For Buttle Lake there appears to have been a sharp decline in the number of oligochaetes (aquatic earthworms), *Pisidium* clams, and amphipod “shrimp” (*Hyalella azteca*) between 1951 and 1964, but again the available early data are poor.

The total catch of emerging insects from the littoral drawdown zone in each of the reservoirs consisted of over 95% chironomids (see Sinclair 1965 for details on methods and results). Clearly throughout the summer of 1964 chironomid emergence was much greater over the flooded trees, brush and other terrestrial vegetation of Lower Campbell Reservoir than over the completely cleared and partially grubbed shore zone of Buttle Reservoir as evidenced by the emergence trap data (Fig. 13) and the surface tow data (Fig. 14).

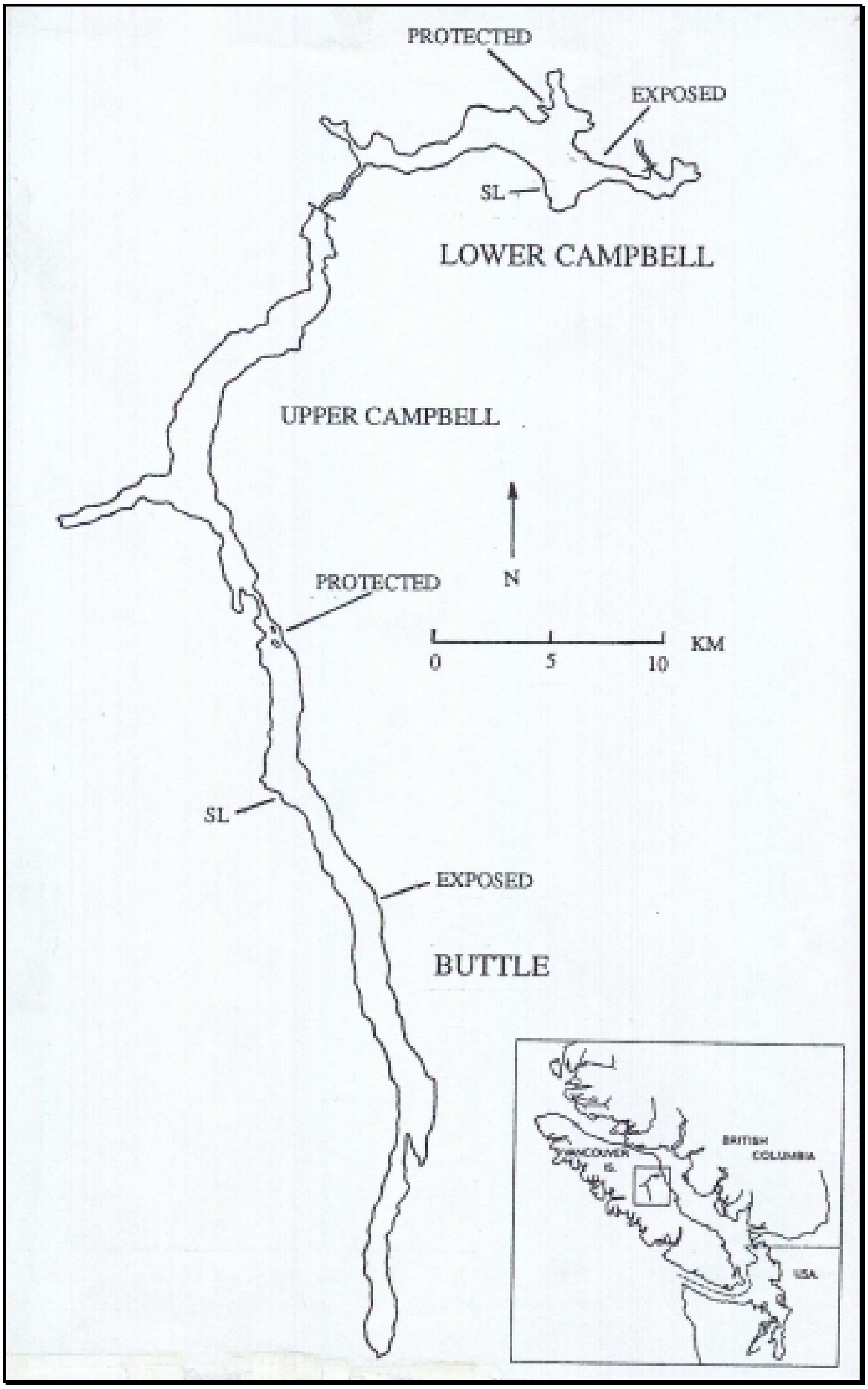


Figure 6. Lower Campbell and Buttle reservoirs showing location of Sinclair (1965) littoral sampling stations (SL) in the drawdown zone and those of T.G. Northcote, 16 October 1996 in exposed and protected littoral sites. Insert shows general location on Vancouver Island, British Columbia.

Replicated series of sweep samples (see Northcote 1996b for method details) were collected from both reservoirs in mid October 1996, selecting a location on each where wave action would be severe and another where it would be minimal (Figs. 6-8). A total of 26 different taxa were identified in the samples (Table 5) with broad representation from many invertebrate groups. There is little doubt that the epibenthic shallow littoral fauna of Lower Campbell Reservoir is both greater in abundance and species richness, whether at the protected or exposed sites, than is that of Buttle Lake. Estimates of invertebrate diversity (Shannon-Wiener H'; Table 5) indicate that the Lower Campbell Reservoir was generally more diverse than that from Buttle Lake. The protected area site on Buttle Lake site had an estimated H' value of 2.558 which was similar to the Lower Campbell protected site value (H'=2.472; Table 5). This result is attributable to fact that the Buttle site had very even distribution amongst the four of the ten species present while the protected Lower Campbell site had an even distribution amongst its 21 species. The Shannon-Wiener function is based on information theory and treats these situations similarly (Krebs 1989) however it is very evident that total abundance and species richness (i.e. number of taxa) at these sites differ substantially (Table 5).

At the Lower Campbell Reservoir the epibenthic fauna was clearly more abundant at the protected than at the exposed site (Table 5), but not so at Buttle. Abundance and diversity in the single Lower Campbell Reservoir sample from the protected site where macrophytes were present (*Anacharis canadensis* mainly, with some *Callitriche* spp., *Isoetes* spp., *Juncus* spp., and *Nitella* spp.) were not much different than at the protected site without macrophytes (Table 5), whereas abundance at the Buttle Lake protected site with macrophytes (*Potamogeton richardsonii*) was higher than at the same site without macrophytes.

In summary, the extensive 1964 work by Sinclair (1965) and by the brief study in October of 1996 seem to confirm that high benthic invertebrate abundance and diversity are associated with a flooded littoral zone where trees, brush and shrub vegetation had been left when flooded, compared to that where nearly complete vegetation clearing had been carried out.

Figure 7. Photographs of Lower Campbell Reservoir, Vancouver Island, B.C. Upper: northwestern end at dam, June 1980, about one km from the exposed sampling site. Lower: exposed sampling site, 16 October 1996. Much organic soil material remains around large stumps and flooded brush in the drawdown zone. From TGN slides.

Figure 8. Photographs of the Lower Campbell Reservoir protected littoral sampling site, 16 October 1996. Upper: general view showing mouth of protected bay sampling site. Lower: 2 metre sweep sampling buoys in place at 30 cm depth; 20 cm wide sampling net at right. From TGN slides.

Figure 9. Photographs of the Lower Campbell Reservoir protected littoral sampling site, 16 October 1996. Upper: taking a 2 m sweep sample at 30 cm depth parallel to shoreline. Lower: old growth coniferous stumps near protected bay mouth; note fine organic matter remaining on bottom around stumps in drawdown zone. Prints from Mrs. B. Ericsson, formerly Institute of Freshwater Research, Drottningholm, Sweden.

Figure 10. Photographs of Buttle Lake and Upper Campbell Reservoir, Vancouver Island, BC. Upper: aerial view of the northern portion of Buttle Lake at its junction with Upper Campbell Reservoir; reservoirs are at near full pool level, June 1980; 16 October 1996 protected littoral sampling site is near islands in left centre. Lower: A lower elevation aerial view of the northeastern shoreline of Buttle Lake near full pool level in June 1980; 16 October 1996 protected littoral sampling site (see Figure 6). From TGN slides.

Figure 11. Photographs of Buttle Lake protected littoral sampling sites on 16 October 1996. Upper: Buttle Lake at protected littoral sampling site, near lower drawdown level; ducks and Canada geese evident in mid-left of photograph had been feeding along shoreline in a scattered stand of macrophyte growth. Lower: close-up of littoral bottom showing 2 m span of sweep sampling transect at 30 cm depth with *Potamogeton richardsonii* growing on a small patch of fine organic sediment. From TGN slides.

Figure 12. Photographs of Buttle Lake exposed littoral sampling sites 16 October 1996. Upper: general view of the exposed littoral sampling site on point of mid-eastern shoreline of reservoir; note people on beach about 50 metres north of site, giving scale to the extent of organic soil loss around large conifer stumps cut as close to ground level as possible before flooding. Print from Mrs. B. Ericsson. Lower: Shoreline of Buttle Reservoir at exposed littoral sampling site showing extent of organic soil loss from the drawdown zone completely cleared and grubbed before impoundment. From TGN slide.

Table 3. Water quality analyses[a] of littoral zone surface water at exposed and protected sites at Lower Campbell Reservoir and Buttle Lake, Vancouver Island, B.C., 16 October 1996.

Water quality parameter	**Lower Campbell Reservoir**		**Buttle Lake**	
	Exposed	**Protected**	**Exposed**	**Protected**
Water temperature (°C)	12.7	12.8	12.3	13.8
Water colour (Pt units)	2	0	0	36
pH	6.50	6.48	6.25	6.38
Conductivity (*u*S/cm at 25°C)	48.6	49.5	62.4	57.5
Total dissolved solids (mg/L)	24.3	24.7	31.1	28.7
Phosphate (P *u*g/L)	10	< 10	< 10	< 10
Nitrate (N *u*g/L)	30	40	30	20
Copper (mg/L)	0.02	0.03	0.03	0.06
Chromium^{+6} (mg/L)	< 0.00	< 0.00	< 0.00	< 0.00

[a] parameters (except on site temperature) determined after two day refrigerator storage by DR 2000 spectrophotometric analyses (Hach instrumentation, techniques in TGN laboratory).

Table 4. Maximum abundance (number/m^2) of dominant faunal groups of benthic invertebrates found in the upper littoral zone of Lower Campbell Reservoir and Buttle Lake.

Dominant faunal group	**Lower Campbell Reservoir**			**Buttle Lake**	
Survey year (Years from impoundment)	**1937[a] (-12)**	**1951[b] (+2)**	**1964[c] (+15)**	**1951[b] (-7)**	**1964[c] (+6)**
Aquatic earthworms (oligochaetes)	0	0	134	955	229
Leeches	19	0	0	0	19
Planorbid snails	38	0	0	0	0
Lymnaeid snails	0	0	0	< 95	0
Pisidium clams	95	0	0	> 1910	38
Hyalella azteca	38	0	0	1910	0
Caddisflies	0	0	0	< 95	0
Chironomid midges	0	287	19	0	115

[a] from Carl (1937) in McMynn and Larkin (1953); area sampled not given but probably 523 cm^2, so numbers multiplied by 19.1 to express in per m^2 values; before impoundment in 1949.
[b] from McMynn and Larkin (1953); 2 years after impoundment.
[c] from Sinclair (1965); 15 years after impoundment.

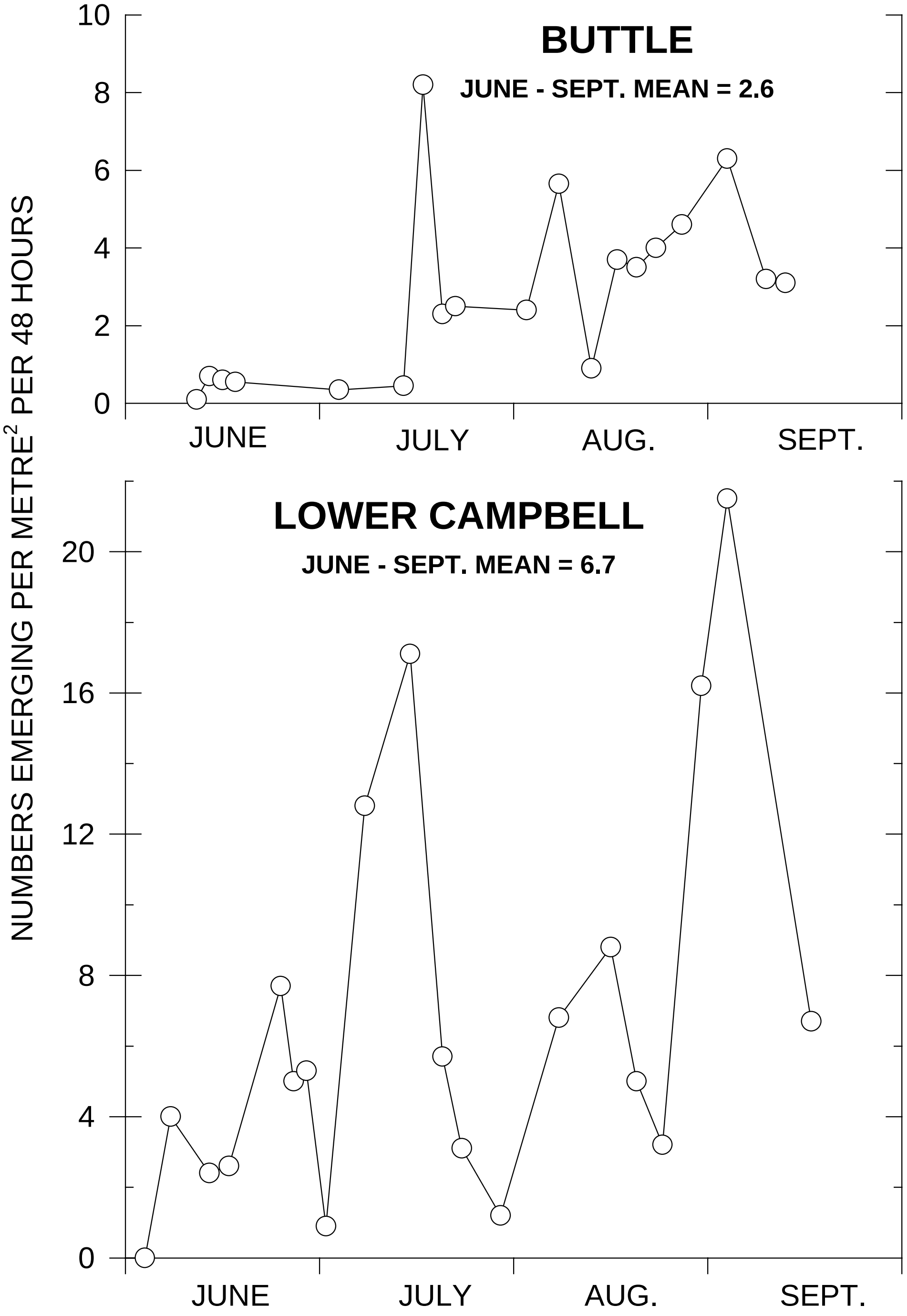


Figure 13. Summer chironomid emergence in the littoral drawdown zone of Lower Campbell Reservoir and Buttle Lake, 1964. Adapted from Sinclair (1965).

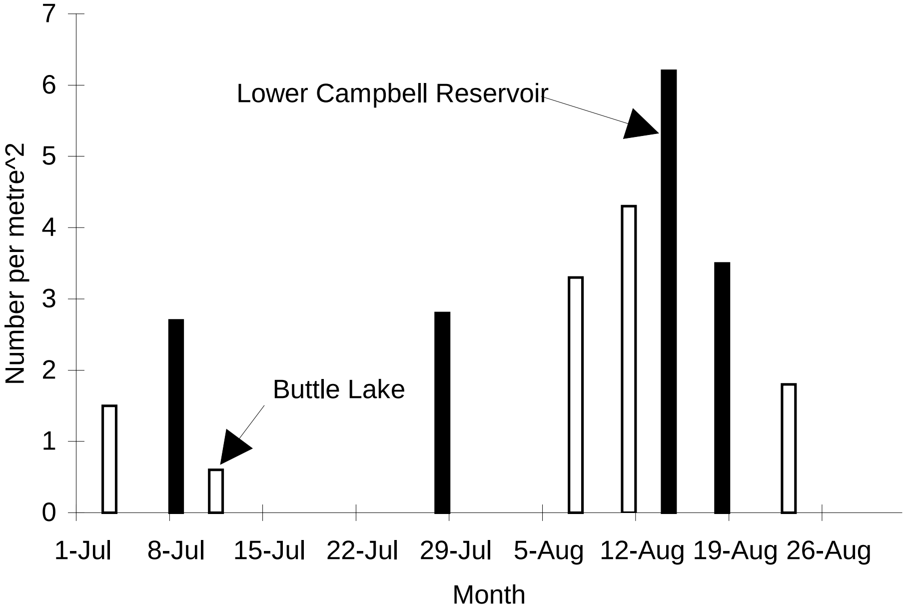


Figure 14. Total surface density of emerging chironomids at three littoral drawdown stations in Lower Campbell Reservoir and Buttle Lake during July and August, 1964. From data in Sinclair (1965).

Table 5. Abundance (mean[a] number per m^2) and diversity (total number of taxa and Shannon-Wiener Function[c]) of epibenthic invertebrates by sweep net sampling at exposed and protected littoral zone sites (0.3m depth) at Lower Campbell Reservoir and Buttle Lake, 16 October 1996.

Taxa	**Lower Campbell Reservoir**		**Buttle Lake**	
	Exposed	**Protected**	**Exposed**	**Protected**
Hydra	--	41	--	--
Nematodes	72	98	3	5
Oligochaetes	109	384	48	45
Snails	11	1	--	--
Bivalves	2	1	--	--
Ostracods	74	22	17	7
Chydorids	99	505	--	2
Daphnids	6	2	2	--
Copepods	15	15	2	--
Amphipods	32	5	2	2
Mayflies	2	2	--	--
Damselflies	--	1	--	--
Stoneflies	1	--	--	--
Corixids	3	--	--	--
Caddisflies	29	15	2	14
Beetles	--	1	--	--
Ceratopogonids	15	270	--	3
Chironomids	241	662	99	54
Other dipeterans	1	9	--	40
Aquatic mites	3	2	1	8
Total number/m^2	715	2036	176	180
Total taxa[b]	19	21	9	10
Shannon-Wiener Function H' (Index of Diversity)[c]	2.922	2.472	1.740	2.558

[a] mean of 3 replicated samples.
[b] some taxa subdivisions not shown above.
[c] Shannon-Wiener Index from Krebs (1989).

10.0 THE FALLS RIVER RESERVOIR CLEARING STUDY

In 1930, a small hydroelectric dam was built on the Falls River, about 53 km southeast of Prince Rupert, British Columbia, creating a 4 km^2 reservoir. The uncleared and flooded macrovegetation was largely western red cedar, yellow cedar (*Chamaecyparis nootkatensis*), western hemlock, balsam poplar (*Populus balsamifera* spp.) and Sitka spruce. In 1981, B.C. Hydro in its redevelopment plan for the dam operation was requested to remove dead or dying trees currently standing in the reservoir and forebay (Bradley 1983) and before doing so had a brief survey conducted in July 1982 on the impact of wood debris and standing trees on productivity of the reservoir (Anonymous 1983). The reservoir water had low turbidity (1.8 - 2.1 NTU), pH (6.3 - 6.7), total phosphorus (<5 *u*g/L) and nitrate nitrogen (7 - 15 *u*g/L). Apart from localized increases in turbidity, no water quality problems were anticipated from reservoir lowering and standing timber removal (Bradley 1983), but the validity of this assumption was not demonstrated. The effects on benthic invertebrate production in the reservoir were considered major and arose from (1) short-term impacts of drawdown to cut and remove standing flooded vegetation; (2) long-term loss of the invertebrate community living on submerged tree surfaces. Three other long-term effects considered were (1) reduced dampening of wind-action by the standing vegetation on bottom sediments, and thereby increased turbidity; (2) an increase in biological oxygen demand after reservoir reflooding; (3) a lowering of primary production in the reservoir as a result of increased turbidity.

The periphyton and invertebrate communities associated with the surfaces of standing flooded timber in the reservoir was shown to be rich in diversity and abundance (Anonymous 1983). Stomach analysis of 12 cutthroat trout (3 - 5 year olds) and 14 Dolly Varden char (*Salvelinus malma*; 2 - 3 year olds) showed that 60% of prey (mainly chironomid larvae and mayfly nymphs) taken by cutthroat were also found on the submerged tree surfaces. About half of the prey items taken by Dolly Varden char were only associated with such surfaces. In conclusion it was suggested that the habitat provided by the standing flooded vegetation was highly important to production of these two species of salmonids.

11.0 THE NECHAKO IMPOUNDMENT

In 1950, the provincial government of British Columbia granted a water license to the Aluminum Company of Canada (Alcan) to divert the Nechako River headwaters, mainly lying in Tweedsmuir Provincial Park, to a Pacific coastal inlet (Gardner Canal) at a hydroelectric power generating station on the tributary Kemano River (Fig. 15). The provincial Game Commission received very small funding and a very short time window to conduct evaluation of the effects of this massive and complex project on both sport fisheries and wildlife resources. Considering this, it is truly remarkable that the reports on the evaluation covered as much as they did (Lyons and Larkin 1952, Hatter 1952), but it is also lamentable that they could not have been more comprehensive, incisive, and quantitative. Since then, literally metres of reports, reviews, reviews of reviews, publications, public and non-public documents and other material on the project have been prepared - some of fine quality and much of mediocre or questionable value - but in totality nearly a quarter of a million pages (Hartman 1996). It is not within the scope of this paper to attempt another review of this publication morass, but in addition to the first two initial reports noted above, a few other outstanding papers relevant to our topic will be selected, notable among them Efford (1975), Jackson (1984) [dealing mainly with the later Kemano Completion Project], Rosenberg *et al.* (1987), and Hartman (1996), though the latter focuses more on the serious problems in the Nechako River system below the dam than in the impoundment itself.

The 95 m high Kenney Dam on the upper Nechako River impounded a “Great Circle” of large lakes forming a reservoir about 890 km^2 in area, flooding 334 km^2 of terrestrial vegetation, with a mean annual fluctuation of 2 m and a maximum of 5.2 m (Efford 1975, Rosenberg *et al.* 1987). The lakes were surrounded by a spruce-balsam climax forest (Hatter 1952) - *Picea glauca*/*Abies lasiocarpa* - with lodgepole pine (*Pinus contorta*) on north facing slopes and a more open seral deciduous association with lowland willow and aspen on south facing shores formed not only by exposure but also by native Indian fires (Hatter 1952). There were extensive areas of marsh and swamp habitat for moose (*Alces alces*), beaver (*Castor canadensis*) and muskrat (*Ondatra zibethica*) along rivers joining the lakes as well as the lakes themselves (Fig. 16), but Hatter (1952) gives no quantitative data on their area. Alcan was required to clear navigation channels in the reservoir between the lakes at a cost not to exceed $250,000 and since the 1970s an additional $500,000 annually has been spent on underwater clearing (Rosenberg *et al.* 1987), using a specially designed barge (Anonymous 1971).

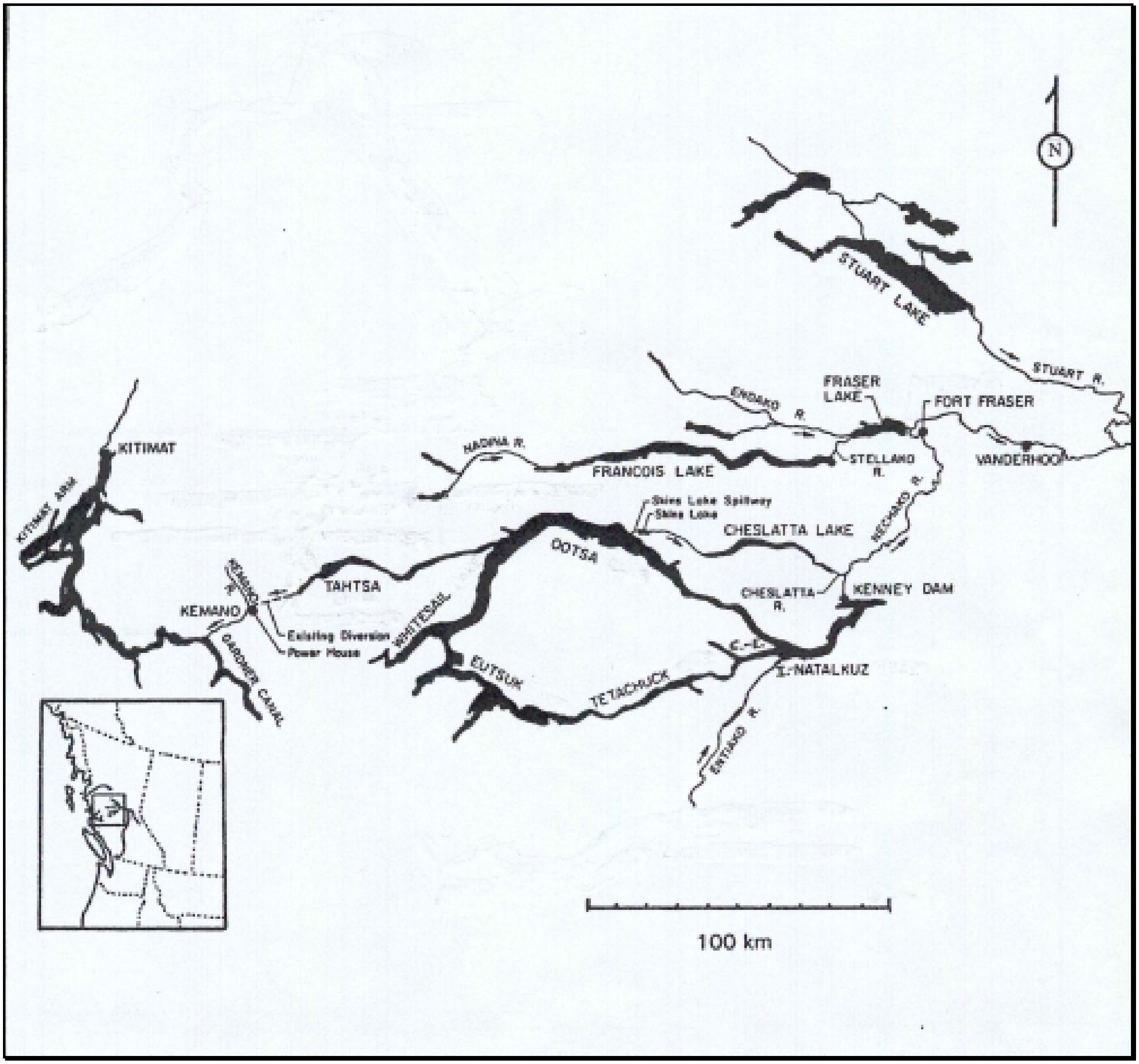


Figure 15. The Nechako Reservoir formed by Kenney Dam on the upper Nechako River, its six major depressions (Intata-Natalkuz, Ootsa, Tahtsa, Whitesail, Eutsuk and Tetachuck) and one minor depression (Chelaslie-Euchu) named after the former lakes and connecting rivers. Adapted from Hartman (1996).

Figure 16. Photographs of Eutsuk Lake prior to impoundment, August 1951. Upper: Eutsuk Lake shoreline near Sand Cabin. Note moose near middle centre. Lower: Aerial view of Eutsuk Lake shoreline area near Sand Cabin with extensive marsh and backwaters. From J.C. Lyons / P.A. Larkin slides in the B.C. Fisheries Branch Research Section collection.

Table 6. Approximate[a] morphometric parameters for the main lakes / reservoir depression regions in the upper Nechako system before and after formation of Nechako Reservoir, taken from Lyons and Larkin (1952); lake and depression sequence given in counter clockwise order from Kenney Dam.

Lake or reservoir depression	Lake before impoundment				Reservoir depression		
	Area (km^2)	Max. water depth (m)	Mean water depth (m)	Shore-line length (km)	Water level increase (m)	Area (km^2)	Area increase (fold)
Intata, Natalkuz	9, 28	25, 18	4.1, 4.9	42, 58	45.7, 47.5	241	6.5
Nechako River					ca 85		
Ootsa	124	85	24.3	174	40.8	337	2.7
Tahtsa	53	217	61.0	73	5.5	124	2.0
Whitesail	113	289	76.2	130	32.3	181	1.0
Sinclair	7	20	6.1	29	39.9	70	10.0
Eutsuk	241	305	107	196	0	241	0
Tetachuck	49	61	15	85	1.5	> 49	> 1
Chelaslie	7	46	< 15	20	45.7	73	2.0
Euchu	25	47	12.2	48	46.3	[b]	

[a] there is considerable variation in values given for these parameters in reports and publications.
[b] value for Chelaslie and Euchu combined.

The lakes in the upper Nechako River system subject to impoundment by Kenney Dam varied greatly in their area, maximum and mean depths, as well as in their shoreline lengths and the increase in water level they experienced (Table 6). Several near the eastern arc of the Great Circle such as Intata, Natalkuz, Chelaslie and Euchu were relatively small in area, circumference and depth but nevertheless were raised over 45 m in level. The one small lake - Sinclair - at the western side of the arc also was raised nearly 40 m and the one intermediate sized lake there - Tahtsa - was only raised 5.5 m. Two large lakes forming the western and northern margins of the Great Circle - Whitesail and Ootsa - each well over 100 km^2 in area (Table 6), were raised over 40 and 32 m respectively, whereas the level of the largest lake in the system - Eutsuk (241 km^2), with a maximum depth of over 300 m and a mean depth of over 100 m, was unchanged. Not unexpectedly, several of the smaller lakes in the system (Intata, Natalkuz, and Sinclair) whose levels were raised appreciably, had surface area increases of over six to ten fold. Surface areas of several intermediate and large lakes were about or more than doubled (Table 6), so a massive amount of terrestrial vegetation was flooded by the project leaving a gigantic waterscape in the park studded with dead trees and woody debris (Fig. 17).

Most of the Great Circle and associated lakes had relatively clear, highly transparent water in midsummer with Secchi disc readings ranging up to 10 or more metres (Table 7), indicating low phytoplankton production and little glacial influence. The one exception, Tahtsa Lake with very low transparency, lying in a narrow glacial valley and receiving large amounts of glacial silt in summer, cleared later in the season (Lyons and Larkin 1952). Its low summer transparency was a result of fine inorganic sediment input so its productivity would be even lower than that in the other lake basins. All the intermediate and large sized lakes in the system had low summer mean temperatures ranging from six to just over nine ^{o}C, so their thermal features were not conducive to high production. Some of the smaller lakes (Intata, Natalkuz, and Sinclair) had intermediate summer mean temperatures (12 to 16^{o}C) which could have promoted higher productivity. Total dissolved solid contents of the lakes ranged between 48 and 60 mg/L, again indicating low to moderate productivity at best (Northcote and Larkin 1956). Nevertheless several of the Great Circle lakes provided very good fishing for salmonids (mainly rainbow trout) with moderately high growth rates (Lyons and Larkin 1952). These workers also made rough estimates of sport fish production for the lakes in pounds per acre per year (approximately equal to kg/ha/year); three of the lakes (Tahtsa, Whitesail and Eutsuk) were very low at 0.2 kg/ha/year, five were intermediate at 0.75 to 1 kg/ha/year (Ootsa, Intata, Natalkuz, Sinclair and Chelaslie), and two were higher at 2 kg/ha/year (Tetachuck and Euchu).

Post-impoundment studies on fish populations of Nechako Reservoir, at least in terms of solid quantitative data, are surprisingly sparse and inadequate. That compiled in 1984 by Envirocon (Anonymous 1984) was considered by a number of MELP biologists to be inadequate (K.I. Ashley responses to Provincial Questions Kemano Completion Project - Reservoir Impacts). Limited catch data (gill net, Gee traps, electrofishing) are available from the Nechako Depression near Kenney Dam for November 1989 and in Tahtsa Narrows for June, August and October 1989 (Anonymous 1993) giving catch percentages for various species. Ten small, unnamed lakes tributary to the Whitesail Depression were inventoried by SKR Consultants Ltd. during the fall of 1995 as part of the Forest Renewal BC operational inventory program (Anonymous 1995). These lakes were independent from the Nechako Reservoir and as such were separate systems and their applicability to this review is limited.

Figure 17. Photographs of Ootsa Lake pre-impoundment (July 1951) and post-impoundment (September 1994). Upper: Ootsa Lake shoreline, July 1951, before impoundment. From a J.C. Lyons / P.A. Larkin slide, in the B.C. Fisheries Branch Research Section collection. Lower: Ootsa Depression, Nechako Reservoir, 20 September 1994, showing a small part of the mainly coniferous flooded forest (over 200 km^2 in all) resulting from its 40.8 m increase in water level. From a G.F. Hartman slide.

Table 7. Some available summer limnological parameters for the main lakes in the upper Nechako River system before the formation of the Nechako Reservoir. Adapted from Lyons and Larkin (1952).

Lake	**Secchi disc transparency (m)**	**Mean water temperature (^{o}C)**	**Total dissolved solids (mg/L)**	**Zooplankton[a] volume (cm^3)**	**Zoobenthos[b] abundance**
Intata	7.6	16.5	48	1.0	--
Natalkuz	9.4	12.4	--	0.5	sparse-many
Ootsa	3.0-10.0	7.7-9.4	60	2.8	sparse
Tahtsa	0.9	6.0	60	5.7	sparse
Whitesail	10.0-14.9	7.1	56	0.9	sparse
Sinclair	7.6	13.8	--	0.4	--
Eutsuk	8.5	7.3-7.9	56	3.1	sparse
Tetachuck	9.4	7.5	“low”	1.5	sparse-few
Chelaslie	4.6	2	“low”	--	--
Euchu	10.0	10.1-13.1	c	1.3	--

[a] mean settled volume (cm^3) from 9 m vertical tow.

[b] 0 “sparse” 🖫 5, 5 “few” 🖫 15, 15 “many” 🖫 50;
Sampling area not given but probably 523 cm^2.

[c] ”relatively low”.

In total the fish community of the major lake system is composed of 10 species (three salmonids, two cyprinids, two catostomids, one gadid and two cottids; Table 8). Two other cyprinids, lake chub (*Couesius plumbeus*) and redside shiner (*Richardsonius balteatus*) have been recorded in lakes tributary to the Whitesail Depression (Anonymous 1995). Of the 40 native species of fish in the Fraser River system (McPhail and Carveth 1992), 29 occur in the middle Fraser subregion into which the Nechako River flows. Thus in terms of species richness the main lakes or depressions of the Nechako Reservoir seem depauperate with only 10 species being recorded (Table 8). Notably absent are white sturgeon (*Acipenser transmontanus*), chinook salmon (*Oncorhynchus tshawytscha*), lake whitefish (*Coregonus clupeaformis*), pygmy whitefish (*Coregonus coulteri*), brassy minnow (*Hybognathus hankonsoni*), longnose and leopard dace (*Rhinichthys cataractae* and *R. falcatus*), and bridgelip and white sucker (*Catostomus columbianus* and *C. commersoni*). Of the three species of salmonids present, all commonly require access to tributary streams with suitable gravel for spawning habitat so their populations may have been more adversely affected by impoundment than the other non-salmonid species which can spawn in lakes.

As is evident in several other large Canadian hydroelectric impoundments (Northcote 1996a), fish at upper trophic levels in the food web have become contaminated with heavy metals, especially mercury. Approximately 13% of the rainbow trout from Nechako Reservoir exceed the guideline of 0.2 mg/kg mercury established by Health and Welfare Canada for humans who consume large quantities of fish (Anonymous 1993). Furthermore sediment samples from the reservoir had four times the mercury concentration found in control lakes, and deep water samples had double that in control lakes (Anonymous 1993).

Table 8. Fishes[a] recorded[b] in main lakes and depressions of the Nechako Reservoir.

	Reservoir Depression							
Fish Species	**Intata/ Natalkuz**	**Ootsa**	**Tahtsa**	**Sinclair**	**Whitesail**	**Eutsuk**	**Tetachuck**	**Chelaslie-Euchu**
Salmonids (Salmon, trout and char)								
Mountain whitefish	1,2	1	1,2	1	--	1	1	1
Rainbow trout	1,2	1	1,2	1	1	1	1	1
Kokanee	1	1	2	1		1	1	1
Cyprinids (Minnows)								
Peamouth chub	2	--	--	--	--	--	--	--
Northern squawfish	1,2	1	2	--	--	1	--	1
Catostomids (Suckers)								
Longnose suckers	1,2	1	1	--	--	1	--	1
Largescale suckers	1,2	1	1	--	--	1	--	1
Gadids (True cods)								
Burbot	1,2	1	2	--	--	1	--	1
Cottids (Sculpins)								
Prickly sculpin	2	--	2	--	--	--	--	--
Slimy sculpin	2	--	2	--	--	--	--	--

[a] follows AFS (1991) common names list.
[b] where 1 = Lyons and Larkin (1952), 2 = Triton Environmental Consultants (1989).

12.0 RESERVOIR TIMBER HARVESTING

Removal of standing, floating and sunken trees in reservoirs whether for commercial purposes or for environmental mitagatory measures, or both, needs to be very carefully considered and conducted to minimize further negative alteration to fish habitat. Promotional articles on techniques for underwater logging in reservoirs have appeared since the early 1970s. See for example Anonymous (1971) for the Nechako, Hatton *et al.* (1976) for the Williston and Dabbs (1996) for the Stave in B.C., Fowler (1979) for the Wyman in Maine, and Malyshev and Shkundin (1988) for reservoirs in Russia. Surprisingly few well documented studies have been conducted on ecological effects of timber salvaging in reservoirs. One in Quebec (Bolullo 1980) and one in Maine (Moring *et al.* 1982) are notable exceptions. Neither of these are highly relevant to problems that may be faced in the Nechako Reservoir. Obviously effects will depend heavily on the reservoir conditions, on size, age and type of timber to be removed, on time after impoundment, on salvaging techniques and timing, and on fish species of concern. Although detailed review and evaluation of these and other related factors were not within the scope of this report, some general remarks can be made for the Nechako Reservoir.

In the first place, harvesting should initially at least be done only in a few carefully selected locations which have been set up with before, during and after monitoring of water quality conditions, primary and secondary production estimates for the benthic and planktonic communities that may be affected, and on relevant features of the fish community. These should also be coupled with similar studies on nearby appropriate control sites.

Because loss of river and stream habitat has been one of the serious effects of the Nechako system impoundment, it would seem prudent to prohibit timber salvaging operations from bays or areas near entrance of tributaries so as to minimize any further negative effects on these and to restrict dispersion of any unfavorable water quality effects more broadly in the reservoir.

Although the scale of drawdown in the Nechako Reservoir is much less than that in the Campbell River reservoirs, nevertheless there could be serious shoreline erosion problems resulting from open season wave action (long fetches with loss of standing tree dampening) and severe winter - early spring ice-off scouring. Therefore size and location of clear or selective cut openings should be carefully considered beforehand and potential effects monitored afterwards.

Removal of standing, floating and submerged trees from the Nechako Reservoir will surely reduce littoral surface areas available for periphytic and invertebrate colonization, as well as lower habitat complexity. Thereby it probably will lower diversity, abundance and production of the benthic invertebrate community. This in turn would certainly affect feeding, growth and production of most members of the fish community.

In all reservoir depressions except Tahtsa, Eutsuk and Tetachuck (Table 6), water level increases after impoundment exceeded 30 m, in many cases were over 40 m, and in the Nechako River depression exceeded 80 m. Consequently large volumes of standing trees occur in the reservoir at depths well below that at which primary production can occur. Harvesting of these would have less impact on productive fish habitat (not considering any unfavorable effects on water quality conditions) than would harvesting in the more productive flooded littoral zone, tentatively estimated to be in the upper 25 m. Disposal of tree root wads once the trunks are removed in harvesting should be in the euphotic zone to obtain advantages of periphytic primary production with attendant secondary epibenthic invertebrate production that can be cropped by the fish community as well as to provide fish habitat complexity. Nevertheless such debris should be placed at levels deep enough to avoid forming navigational hazards at low water level or being disturbed by wave action. Useful guidelines for reservoir debris management are being developed by B.C. Hydro (Anonymous 1996) but at present do not seem to consider effects which may result from reservoir timber harvesting or its implications for fish habitat and production.

13.0 RESEARCH AND MANAGEMENT RECOMMENDATIONS

The research that is still so badly needed on the system must be carefully honed to management needs in an experimental manner. If that is done then the questions being probed, no matter what the “answers” that may be supplied, can be used in a far more responsive and instructive way to better “manage” this heavily perturbed ecosystem, but still one with much potential. The following suggestions are prioritized into primary and secondary needs, but not in the subdivisions within these needs.

13.1. Some initial primary needs

First, we are dealing here with a reservoir surface area of nearly 900 km^2, with some 334 km^2 of terrestrial vegetation flooded nearly half a century ago, and still being affected by a tributary drainage area of nearly 14,000 km^2 - nearly two and a half times the area of the province of Prince Edward Island. We apparently lack basic quantitative data on reservoir morphometry (bathymetric mapping, shoreline sinuosity and surface area at full pool and maximum drawdown levels, as well as the type and area of vegetation that was flooded. Apparently a large echosounding data file is available and should be used for the above purposes and for fish abundance estimates if possible (personal communication Brian Fuhr, MELP, Smithers).

1. **Satellite imagery at reservoir low water period combined with Geographic Information Systems (GIS) analysis.**

Dr. Hans Schreier, Institute for Resources and Environment, University of British Columbia (UBC) should be contacted for involvement along with some of his graduate students as well as faculty and students at UNBC, to work up basic descriptive information, reservoir depression by depression, on present conditions in the littoral zone.

2. **Quantitative estimates of fish abundance (by species and size if possible) in the littoral and pelagic zones by echo sounder / integration systems.**

Use of high frequency sounder and echo integrating devices with vertical and side-scanning transducers on day and night transects, reservoir depression by depression should be explored. We fully appreciate that the flooded littoral vegetation will give great difficulties in such work, but the problems are not insurmountable.

3. **Standard quantitative estimates of fish species, sizes and populations in the littoral and pelagic zones.**

Recommendation (2) should be tied in with well replicated and standardized estimates of fish species, size and abundance in selected littoral portions of each reservoir depression using gill nets, traps and boat-operated electrofishing gear (see Knight and Bain 1996) over day and night periods during three seasonal periods (spring, summer, and autumn).

4. **Epibenthic invertebrate abundance and diversity**

Information on epibenthic invertebrate abundance and diversity should be obtained, reservoir depression by depression, in replicated representative sampling by the sweep net technique (see Table 5) at shallow depths (30 - 50 cm) in the littoral zone bottom and on the surfaces of stable standing vegetation trunks using a modified sweep or suction sampler. Sampling should be stratified on sections heavily covered with flooded vegetation and on others with little or no such vegetation, in both protected and exposed sites.

5. **Angler effort and catch per unit effort**

Quantitative data on present angler effort and catch per unit effort should be obtained, reservoir depression by depression, over the seasonal period of angling effort, with stratification as in (4) above.

13.2. Some specific secondary needs

1. Impacts of underwater timber salvaging on fish and fish habitat

Apparently limited underwater timber harvesting has been going on sporadically in certain areas of the Nechako Reservoir for over two decades. This should be classified into the reservoir depressions where conducted within time blocks of say a decade, separating that in the last year as a separate interval. Primary recommendations 2, 3 and 4 could then be applied to selected sites within these areas as well as in selected "control" areas nearby to obtain data on potential effects of such operations on fish and epibenthic invertebrate communities over the time period of operation. Relevant references in the literature review section of this report should be consulted. There might be value in also comparing some easily measured (and inexpensively obtained) water quality data at salvaging sites currently being used, along with nearby control sites. Suggested parameters for measurement would include Secchi disc transparency, vertical water turbidity and conductivity. Much of the literature checked dealt with recovery of sunken small logs in eastern U.S. reservoirs so findings should not be extrapolated to the Nechako system without caution.

2. Comparison of Eutsuk depression with other Nechako depressions

Because former Eutsuk Lake has been minimally affected by impoundment, the opportunity to compare its littoral zone conditions with other depressions in the reservoir should be exploited.

3. Evaluation of a series of small experimental research projects

a) Nutrient enrichment of semi-enclosed bays in the reservoir littoral zone

First see Milbrink and Holmgren (1981). The nutrient levels (nitrogen and phosphorus) in littoral waters of selected bays should be determined in early spring. Based on total dissolved values and geographical location of the reservoir (Northcote and Larkin 1956), these would expected to be moderately low. If so, then a few suitable bays with small inlet inflows for controlled nutrient addition should be selected with paired treatment and control bays in a few of the reservoir depressions. Effects of nutrient additions in the pairs should be followed at biweekly intervals over the late spring to early autumn seasons. Cost and benefit analyses should be conducted to explore this as a long term mitigation or compensation action.

b) Mid-term effects (2-5 year) of selective clearing of some semi-enclosed bays

Set up an experimental test of the effects of different degrees of standing timber clearing in several small semi-enclosed bays in the reservoir littoral zone. Different clearing levels that might be tested include: (a) no clearing, (b)

50% removal of standing timber in patches, (c) 100% removal of standing timber. Effects on water quality, fish abundance and diversity, fishability, and catch per unit effort using different gear types could be monitored (the latter with cooperation of local fishing clubs).

4. Involvement of universities and other agencies in research issues

Dr. Max Blouw, Professor, Biology/Fisheries, University of Northern British Columbia (UNBC), has already expressed interest in involving graduate students in study of the effects of harvesting submerged trees in the Nechako Reservoir. This should be actively encouraged - surely an appropriate subject for FRBC support. Other faculty and students at UNBC should be sought for their participation. Furthermore expertise in other universities and agencies should be solicited. For example at UBC, staff in the Fisheries Branch Research and Development Section should be involved as well as others in the Institute for Resources and Environment, the Fisheries Centre, and the Department of Zoology.

5. Involvement of the angling, recreational and environmental public of the region

What is needed is a series of well designed public information packages on the reservoir - brochures, videos, forums and seminars - to raise public understanding of the complexities and interactions involved. Surely this would be a suitable focus for FRBC support and also for that of Alcan.

6. Assembling an interactive management strategy for the reservoir

Even a casual glance at the preface of this report should convince the most insensitive environmental observer that as a park waterscape, the Nechako Reservoir is an unmitigated disaster. But mitigation of its condition is in part possible and largely should be the moral and financial burden of those who have enjoyed, far from its locale, the profits of that impoundment for nearly half a century! To be sure, as has been documented in this report, flooded terrestrial forest and other vegetation can provide productive habitat for the whole food web leading up to fish, if not higher vertebrates. But that alone is not compensation enough for the reservoir's present condition. What is desperately needed is a serious integrated approach to its restoration, as far as is possible, as a park waterscape within the limits of its use as a hydroelectric impoundment. That will take meaningful participation and financial support for several decades or more of all "stakeholders" who must be involved locally, provincially, nationally, and even internationally as the roots of corporate responsibility spread. The stakelholders should include but not be limited to Alcan, the BC Forest Service, and timber licensees.

The big reservoirs in the Kootenays are covered by the Columbia Basin Fish and Wildlife Compensation Fund. Williston Reservoir is covered by the Peace-Williston Compensation Fund which has supported some 45 different studies on the system along with 11 small lake evaluation reports and 35 small lake reconnaissance surveys in the watershed (Anonymous 1997). That leaves the Nechako Reservoir as the only large one in British Columbia with no secure fund for mitigation/compensation activities. Surely this glaring gap in support and interest should be quickly and handsomely filled!

The challenge is great, but so are the resources, imagination and ingenuity of the stakeholders. And there are factors in their favour. First of all, because of the enormous size of the reservoir, its mean annual fluctuation is not high - about 2 m - so the nearly insurmountable problems of many reservoirs such as Gardiken in Sweden (Fig. 4) with a 20 m annual change in level, should be minimized in Nechako. Much of the near-surface flooded timber can be used for merchantable wood, as has already been shown. Its harvest though should be carefully planned to create areas of better recreational and aesthetic opportunities without damaging the aquatic biota that provide part of that use. To this end the suggestions in the previous two sections should be put to effective action. Restoration of a park waterscape within the reservoir should be concentrated at first in a restricted region, again as an adaptive and interactive test site, to be evaluated, modified and applied to others as results indicate. Most certainly Alcan, the local community, the foresters, the university scholars and students, and the populace of the province and beyond could take profit, pride, and pleasure in such an enterprise!

14.0 CONCLUSIONS

1. Despite a long history of concern and publication on ecological interactions in the flooded littoral zone of reservoirs, there is a surprising lack of information on the role of submerged terrestrial vegetation in relation to fish, fish habitat and fisheries in northern temperate latitudes that can be directly applied to the Nechako Reservoir of British Columbia.

2. Nevertheless submerged trees in the flooded littoral zone of reservoirs, and at deeper levels, undoubtedly serve as fish habitat, though highly altered from that existing prior to impoundment. For the Nechako Reservoir large areas of former interconnecting riverine habitat between lakes, as well as lower reach tributary stream habitat, both highly important for salmonid spawning and early rearing purposes, have been replaced by a massive littoral and sublittoral habitat of high structural complexity mainly useful for fish feeding.

3. In many reservoirs a formerly high productivity region, either a lake littoral zone or a river riparian zone or both, is subjected to severe and abnormal fluctuations in water level, temperature and erosion processes which greatly reduce productive capacity. This reduction is intensified in northern climates and by complete removal of standing flooded vegetation.

4. Very shortly after inundation a predictable sequence in vegetation death and decomposition occurs along with leaching from flooded soils to cause marked changes in water quality parameters. These include dissolved organic matter, humic compounds,

biological oxygen demand, dissolved oxygen, and nutrients which in turn affect primary and secondary production as well as fish growth and production. Timing and intensity of these changes vary considerably with latitude, region, reservoir size, depth, retention time and other factors.

5. Impacts of flooding on terrestrial vegetation are intensely expressed on all levels of the littoral community (primary producers, benthic, epibenthic, and planktonic invertebrates) and thereby on the food web leading to fish.

6. Flooded terrestrial vegetation forms important spawning, juvenile rearing, and adult feeding habitat mainly for warmwater fishes in lower temperate latitudes. Its value in northern latitude reservoirs and fish communities is not well known but still may be considerable.

7. In general fish abundance and harvests are higher in littoral areas of reservoirs with, than without, flooded terrestrial vegetation. Very few studies have been made on north temperate reservoirs with salmonid species.

8. Pre-impoundment preparation of areas to be flooded in many Canadian reservoirs has been directed mainly for non-fisheries purposes (operational needs, navigation and public safety, timber harvesting, aesthetic considerations, and others). Better attention to fisheries requirements will demand much more experimental research on north temperate conditions and fish communities in order to effect appropriate littoral zone treatment.

9. A variety of mitigatory measures have been tried since the early 1940s to ameliorate for fisheries purposes the negative effects of littoral zone flooding in reservoirs. Two that seem promising are (1) selective clearing and leaving of patches of standing vegetation, and (2) controlled nutrient enrichment of protected reservoir bays. Ones that should not be considered are introductions of exotic invertebrates and fishes and fish culture and propagation.

10. Two relevant, though limited, studies on the importance of flooded terrestrial vegetation in British Columbia reservoirs - that on the Campbell River impoundments and that on the Falls River Reservoir - both suggest that such vegetation contributes very significantly to invertebrate productivity of high value for sport fish growth and abundance.

11. Though a plethora of reports, reviews and other publications have been produced regarding the impoundment of the upper Nechako River and the Nechako Reservoir, surprisingly few deal directly with the role of flooded terrestrial vegetation in its littoral zone or the effects of its removal on the fish community (ten species - three salmonids and seven non-salmonids). Because of their mainly stream spawning requirements, the salmonids may have been more seriously affected than the non-salmonids by impoundment.

12. Harvesting of submerged timber in the Nechako Reservoir should be conducted in a very carefully controlled and experimental manner to maximize information gain and to

minimize further negative environmental effects in an ecosystem already heavily impacted for nearly half a century. Several suggestions for this are given.

13. A series of initial primary and specific secondary research and management recommendations are proposed with the aim of rectifying as soon as possible the shocking lack of basic information on the Nechako Reservoir and to manage harvesting of its submerged terrestrial vegetation in a way to provide a productive littoral zone useful and safe for its considerable recreational potential, sport fishing and otherwise.

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