following and other issues: 1) actions to minimize adverse impacts on the resources of the area; 2) the rehabilitation of areas that have suffered resource degradation; 3) the preservation and management of fish and wildlife of the area; and 4) the preservation and management of lakes, ponds, rivers and streams of the area.

The liming of acidic waters is a management activity which is considered as part of the planning for certain state waters. A number of the Unit Management Plans which have been adopted therefore have included liming as a possible management activity. Lakes which are discussed as possible liming candidates in these Unit Management Plans must still however, meet the DEC criteria which are proposed in the revised liming policy. No liming will occur until eligibility has been confirmed and all regulatory requirements have been met. A listing of the Unit Management Plans which have been completed or being prepared is presented in Table 5.

In units where management plans have not yet been completed discussions with the APA will be held prior to any liming projects. Liming and other management activities may occur in these units, but require consultation with the APA and compliance with Memoranda of Understanding between the DEC and APA and State Land Master Plan guidelines.

III. THE ACID DEPOSITION PROBLEM AND ITS IMPACT

A. Description of the Problem

The acid deposition problem has been the subject of hundreds of popular and scientific articles, books, and television programs. The U.S. National Acid Precipitation Assessment Program has spent over 500 million dollars studying the problem, and other countries and private industry have spent additional millions. This tremendous amount of research has answered many questions and given us a much better understanding of how acidic deposition is affecting the environment.

Numerous impacts of acidic deposition have been found to be more complex than originally proposed. However, the basic problem continues to be that air pollution affects aquatic and terrestrial ecosystems. Simply stated sulfur and nitrogen oxides are released from the burning of fossil fuels and combine with water in the atmosphere, forming sulfuric and nitric acids. These acids are often carried great distances in the atmosphere before they fall to the earth as acid rain, snow, or fog. In the eastern U.S. the precipitation may at times be 10 times more acidic than the precipitation which falls in the western U.S. Figure 4 (NAPAP 1987) shows the average pH of precipitation which fell in the U.S. from 1980-1984. (The pH scale expresses acidity on a logarithmic scale ranging from 0 to 14 with pH values less than 7.0 being acid. A change of one pH unit, for example from 6.0 to 5.0 indicates a tenfold increase in acidity.)

Detailed explanations of the acid deposition problem have been presented in other NYSDEC documents (NYSDEC 1984) and will not be

Table 5. Forest Preserve Unit Management Plans completed or in progress.

Region 3
- Balsam Lake Mountain Wild Forest, 1989
- Belleayre Mountain Ski Center, 1985
- Slide Mountain/Panther Mountain Wilderness, 1987

Region 4
- Indian Head - Plateau Mountain Wilderness (in progress)
- Middle Mountain Wild Forest, 1988
- Dry Brook Ridge Wild Forest, 1988
- Windham High Peak Wild Forest (in progress)
- North Mountain Wild Forest (in progress)
- Kaaterskill Wild Forest, 1987
- Cherry Ridge - Campbell Mountain Wild Forest, 1987

Region 5
- Pigeon Lake Wilderness (in progress)
- Jessup River Wild Forest (in progress)
- Pharaoh Lake Wilderness (in progress)
- Hudson Gorge Primitive-Blue Mountain Wild Forest (in progress)
- High Peaks (in progress)
- Saranac Lake Wild Forest/St. Regis Canoe Area (in progress)
- Black Mountain Section, Lake George Wild Forest, 1986
- Lake George Beach and Battlefield Park, 1981
- Mt. Van Hoevenberg Recreation Area, 1986
- Siamese Ponds Wilderness Area, 1987
- Whiteface Mt. Ski Center, 1987
- Gore Mt. Ski Center, 1987
- Hammond Pond Wild Forest, 1988

Region 6
- Grass River Wild Forest, 1990
- Fulton Chain Wild Forest, 1990
- Black River Wild Forest/Pratt-Northam Memorial Park (in progress)
- Aldrich Pond Wild Forest (in progress)
- Pepperbox Wilderness, 1985
- Cranberry Lake Wild Forest, 1985
- HaDeRonDah Wilderness Area, 1986
- Independence River Wild Forest, 1986
- Five Ponds Wilderness, 1987
- Buck Pond Primitive Corridor, 1987
- Wanakena Primitive Corridor, 1987

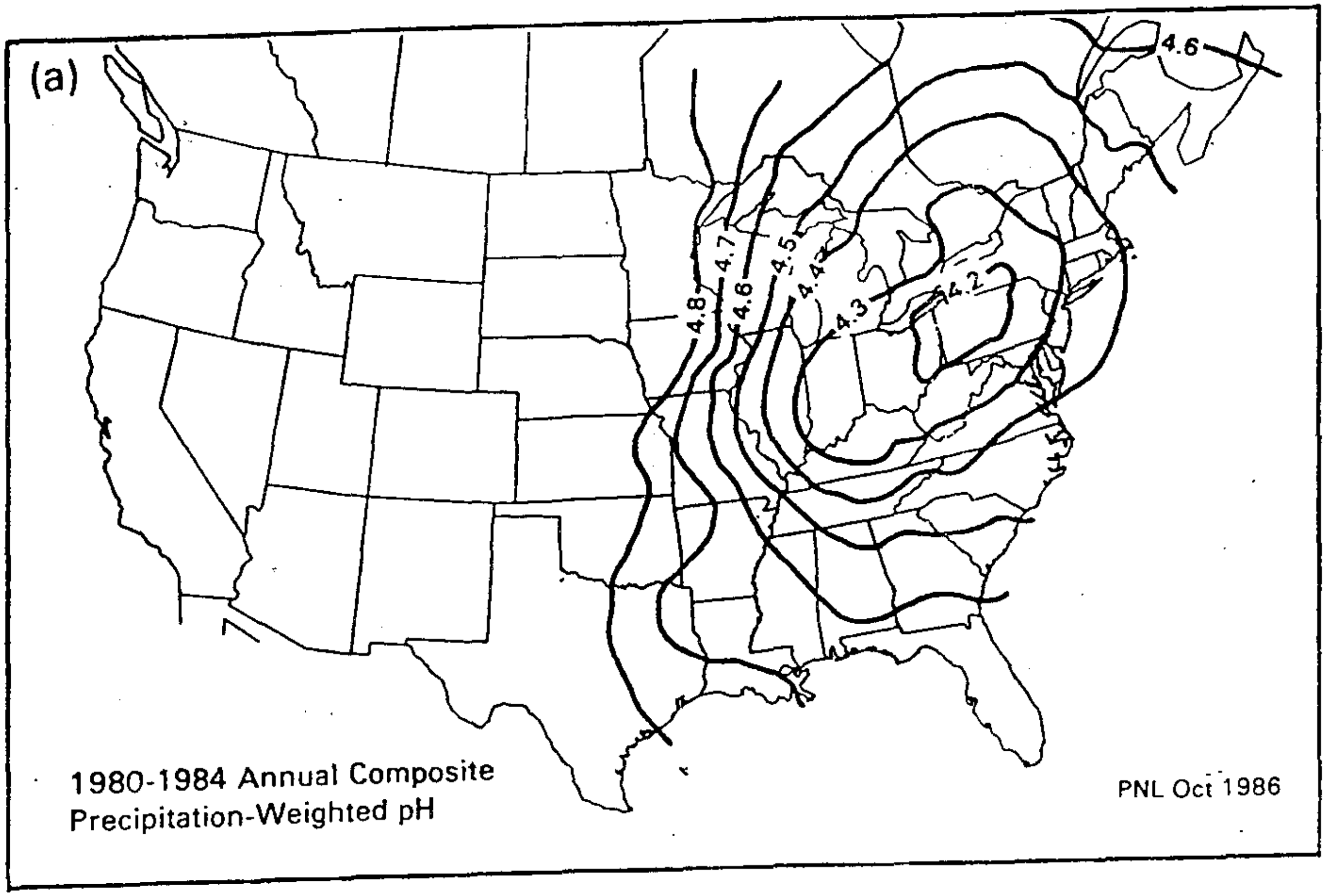


Figure 4. Average pH of precipitation which fell in the U.S. from 1980 to 1984 (figure taken from NAPAP 1987).

repeated here. While the focus of this document is primarily on aquatic ecosystem impacts, there also have been many studies and documented impacts of acid deposition and air pollution on visibility, human health, forests, and damage to structures and materials. These additional impacts and the presence of acid impacted streams are important to keep in mind when discussing the liming of acid lakes to mitigate acidic deposition problems.

Two primary factors are important in determining whether or not a lake or pond will be affected by acidic deposition: (1) the amount of acidic deposition occurring, and (2) the sensitivity of the water and watershed to acidification. Most areas of the northeastern U.S. are receiving high levels of acidic deposition. The lakes which are most sensitive to this acidification are the ones most affected. Lakes and streams in regions where limestone is abundant are relatively insensitive to acidification. The greatest impact has occurred in lakes and streams where the soil and bedrock cannot neutralize the acid.

The effects of acidic deposition on aquatic systems have been documented from many parts of the world. Norway and Sweden have reported large numbers of lakes acidified as a result of acidic deposition. Similarly Canada has found acidic deposition to be a major problem in the acidification of hundreds of its remote waters. Also in Canada it is important to note that when the world's largest emitter of sulfur dioxide, the Sudbury nickel smelter, reduced its emissions by 54%, the water quality of the surrounding lakes improved dramatically (LaZerte and Dillon 1984). When these and other data are examined objectively, it is clear that acidic deposition has had a significant adverse impact on our aquatic resources.

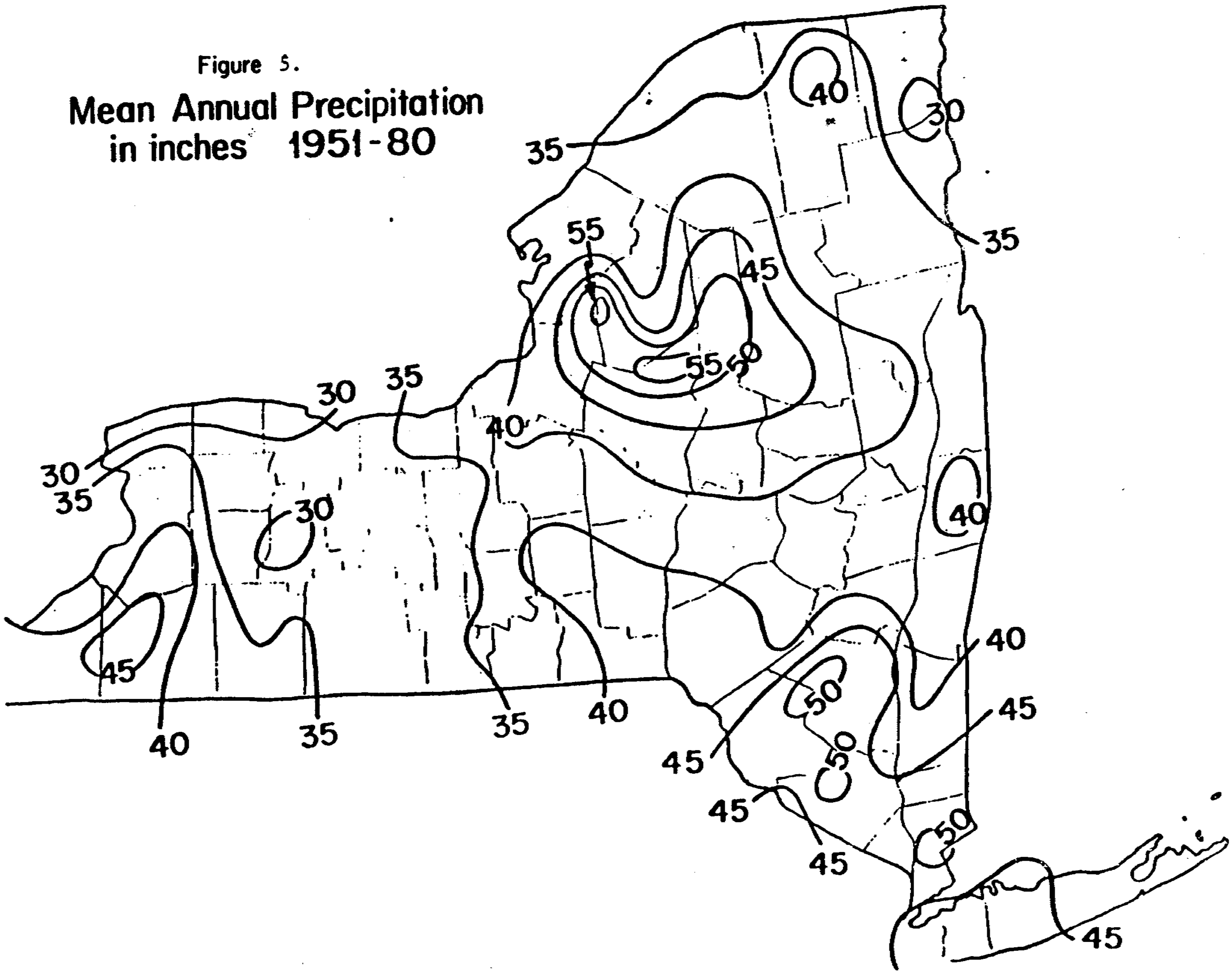
B. <u>Extent of the Problem in New York State</u>

All of New York State is receiving relatively high levels of acidic deposition (NYSDEC 1984). The areas which receive the most precipitation (Figure 5) also appear to receive the most acidic deposition. As discussed above, the sensitivity of the resource to acidification is one of the main factors which determines whether the resource will be adversely impacted. The areas within New York State sensitive to acidic deposition have been identified as part of the State Policy to Reduce Sulfur Dioxide Emissions (NYSDEC 1985). These areas include: (A) central-western Adirondacks, (B) central Catskills, (C) Hudson Highlands, (D) eastern Long Island, and (E) Rensselaer Highlands, and are shown on Figure 6. Acidic and/or low alkalinity waters have been identified in each of these regions.

Schofield (1977) conducted a survey of Adirondack waters thought to be sensitive to acid deposition and found that in the high elevation ponds he surveyed, over 50% of the waters exhibited pH levels below 5.0. Colquhoun et al. (1984) presented a more complete summary of the available water chemistry data for Adirondack and Catskill waters. Their data showed approximately 20% of the Adirondack ponded waters had pH levels less than 5.0.

Figure 5.

Mean Annual Precipitation in inches 1951-80



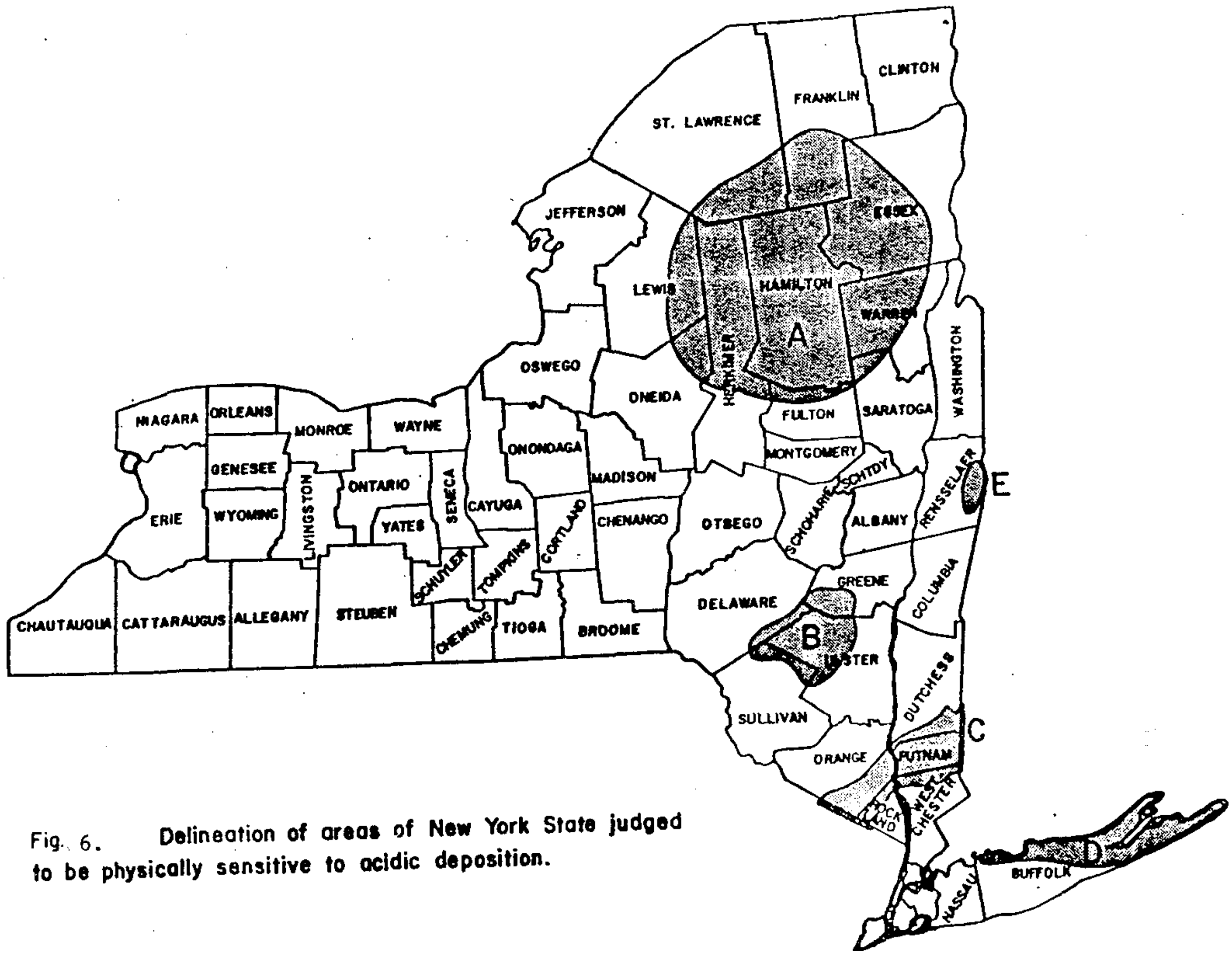


Fig. 6. Delineation of areas of New York State judged to be physically sensitive to acidic deposition.

In an effort to establish a more complete and reliable data base for the Adirondack ponded waters, the Adirondack Lakes Survey Corporation (ALSC) was established in 1984. This corporation, funded by the Empire State Electric Energy Research Corporation and the NYS Department of Environmental Conservation surveyed over 1723 New York waters. The information gathered from each of the surveyed waters included physical, chemical, and biological data. Of the 1469 Adirondack waters surveyed during the first years of the project 352 (24%) had pH levels less than 5.0 (Kretser et al. 1989).

The USEPA also conducted surveys in New York State to assess the extent of the acid deposition problem. In this EPA study, waters less than 10 acres in size were considered unimportant and were not surveyed. The EPA study, because of the omission of sensitive small ponds, found that only 10% of the waters in northern New York had pH levels ≤ 5.0 (NAPAP 1987). There has been considerable criticism of the USEPA study because of this decision not to include small ponds in their survey.

Streams are also being impacted by acidic deposition in New York State and have been widely surveyed (Colquhoun et al. 1981, 1982, 1984; Phillips and Simonin 1987). Although the streams in the Allegheny region were found to be only moderately sensitive to acidification (Phillips and Simonin 1987), the streams in the Adirondacks and Catskills have been shown to be very sensitive (Colquhoun et al. 1984).

Big Moose Lake in the Adirondacks has been studied intensively in relation to acidic deposition and its effects on water chemistry and fish populations. Although the lake once supported viable lake and brook trout populations (Pfeiffer and Festa 1980), the present day fishery is poor, and Johnson et al. (1987) documented water quality conditions toxic to lake trout. Evidence that the lake has indeed become more acidic in recent years was provided by Charles (1984). He studied the diatoms from layers of the lake sediments and reconstructed the pH history of the lake based on the species of diatoms observed at various sediment depths. According to Charles (1984) the pH of Big Moose Lake has decreased steadily from about 5.7 in 1950 to about 4.7 at present. According to Charles (1984) the most reasonable explanation for the cause of the pH decline is strong acid deposition. Deep Lake and Upper Wallface Ponds, also in the Adirondacks, show a similar pH decline which began in the 1930's to 1950's (Charles and Norton 1986).

Woods Lake is relatively close to Big Moose Lake and has been studied intensively as part of the Integrated Lake-Watershed Acidification Study (ILWAS). As part of ILWAS, a complex model was developed to predict changes in surface water acidity given changes in the acidity of precipitation and dry deposition (Gherini et al. 1984). Using this model it was shown that if acidic deposition was reduced by 50% the results would be considerable improvement in the water quality of Woods Lake. The summer pH levels were predicted to increase from approximately 5.0 at present to approximately 6.0 at the reduced deposition level (Gherini et al. 1984).

C. Effects of Acidification on the Ecosystem

1. Water Quality

A consistent characteristic of waters acidified by atmospheric deposition is the replacement of HCO_3^- by $SO_4^=$ with little change in the relative concentrations of cations. Surface water acidification has been attributed to atmospheric deposition of H_2SO_4 and HNO_3, the oxidation of organic nitrogen from the soil, the production of soluble organic acids through the decay of dead plant and animal material in soil, the oxidation of naturally occurring sulfide minerals, and changes in land use.

Many areas in the northeast are sensitive to mineral acidity. Watersheds in acid sensitive regions are usually underlain by granitic bedrock and have little exchangeable or easily weatherable basic cations (Ca^{+2}, Mg^{+2}, Na^+, K^+).

These watersheds are also characterized by an inability to retain inputs of acidic anions ($SO_4^=$, NO_3^-, Cl^-). Therefore, high loadings of acidic anions will not be attenuated in the soil but will be removed from the watershed by drainage water. Anionic solutes must be accompanied by an equivalent charge of cations to maintain electroneutrality (charge balance). Complete neutralization of acidity can be accomplished by the dissolution or exchange of basic cations within the soil.

However, in the absence of readily available basic cations, neutralization will be incomplete, and acidic cations (e.g., H^+, labile monomeric aluminum) will be transported from the soil to the surface water. This process is of concern because high concentrations of acidic cations appear to be harmful to aquatic biota.

In addition to aluminum, elevated levels of cadmium, copper, lead, manganese, nickel, and zinc have been reported in many acidic lakes and streams (Beamish 1974; Conroy et al. 1976; Schofield 1976; Almer et al. 1978; Henrikson and Wright 1978). These increased concentrations of metals may result from either increased atmospheric loading (associated with or independent of acidic deposition) or increased metal solubility caused by increased surface water acidification.

Water clarity also changes in acidic waters, generally increasing. This may be due to many factors including, a reduction in algal biomass, precipitation of organics by aluminum or changes in the light absorption capacity of humic materials. Greater light penetration may allow an increase in macrophyte growth (EPA 1983), and may cause changes in thermal regimes of affected lakes.

2. Algae

Algae comprise the primary producers in most freshwater ecosystems and provide the food for zooplankton and indirectly, fish. Acidified lakes yield less diversified species of both water-borne and benthic algae. Synoptic surveys conducted in Scandanivia, Canada, and the United States have indicated that the species diversity of benthic and planktonic algal communities is less in acidified lakes. Yan and Stokes (1976) observed only nine species of phytoplankton in a single sample from Lumsden Lake (pH 4.4; Beamish and Harvey 1972), in the La Cloche Mountains in Ontario, but observed over 50 species in each of two nearby circumneutral lakes. Diversity indices for phytoplankton populations in the LaCloche Mountain lakes are much less in lakes with pH values below 5.6 (Kwiatkowski and Roff 1976). In Scandinavian lakes numbers of phytoplankton species are also much less in lakes with pH values below 5.5 (Leivestad et al. 1976; Almer et al. 1978).

Although species diversity of phytoplankton generally decreases with increasing acidity, biomass (Yan 1979) and productivity (Almer et al. 1978; Schindler 1980) are often not reduced by acidification. However if phosphorus (the nutrient that normally limits primary productivity in lakes) is immobilized due to complexation with aluminum and humic material (Almer et al. 1978), this would result in reduced primary productivity. Benthic filamentous algae has been seen to increase in the littoral zone of many lakes with a pH of 4.5-5.5. This algae growth may reduce light penetration, restrict fish feeding and spawning and reduce recreational activities.

3. Macrophytes

Information on the effects of acidification on macrophyte communities of soft-water lakes is still incomplete. Scandinavian investigators have suggested that when pH declines, typical macrophyte dominants are replaced by very dense beds of Sphagnum (Grahn et al. 1974; Hendrey et al. 1976). The loss of some macrophyte species and the associated increase in Sphagnum abundance may be indirectly related to depressed pH, through changes in inorganic carbon availability (Raven 1970).

Macrophytes may be indirectly affected by increased metal (Al, Cd, Fe, Mn, Cu, Pb, Zn) concentrations in water and sediments. Aluminum, copper, iron and lead are seen to be elevated in plant tissues from acid waters. These metals are known to be toxic to aquatic plants, but it is not clear if metal uptake decreases productivity. If metal concentrations increase in tissues, but do not inhibit growth, there is a potential for increased cycling of metals (EPA 1983).

4. Zooplankton

Zooplankton communities are comprised of four groups of animals: protozoans, rotifers, crustaceans and insects. Zooplankton are an intermediate link in the aquatic food chain, being an important food source for young fish. Acidification apparently results in reduced zooplankton biomass, as both the numbers and average size of community members are reduced (Yan and Strus 1980). As a result food availability to higher trophic levels may be decreased.

Acidification of lakes is accompanied by changes in the occurrence, abundance and seasonal succession of species, and in the diversity of crustacean and other zooplankton. It is often assumed that the direct cause of these changes is differences in tolerance among zooplankton species to increased H+ concentration. However, *acidification also increases transparency of lakes, increases* the concentration of potential toxicants such as cadmium (Almer et al. 1978) which is toxic to zooplankton at less than 1μg/l (Marshall and Mellinger 1980), and produces quantitative and qualitative changes in zooplankton predator and prey species (Harvey et al. 1981). Therefore, the immediate causes for the changes in zooplankton communities that do occur, while linked to increased acidity, may be quite complex.

The diversity of zooplankton communities has been reported in several studies to be greatly reduced by acidification (Sprules 1975; Raddum et al. 1980). Whereas nonacidic lakes typically contain approximately ten species of planktonic crustacea in mid-summer collections, Sprules (1975) observed that the number of species and species diversity of acidic lakes in the La Cloche Mountains in Ontario was drastically reduced. In several cases only a single species, Diaptomus minutus, remained.

5. Macroinvertebrates

Many invertebrates are very sensitive to pH levels. Snail populations become stressed below pH 6.0 and are eliminated below pH 5.2. The documented effects of decreased pH include the disappearance of Mysis relicta in Lake 223, an experimentally acidified lake in the Experimental Lakes Area of Ontario (Malley et al. 1982), elimination or reduction of Ephemeroptera populations in a stream in the Hubbard Brook Experimental Forest in New Hampshire (Fiance 1978; Hall et al. 1980). Those species with acid-sensitive life stages (such as emergence in insects) which can coincide with low pH snowmelt, or other events, such as low pH flushing, may be especially sensitive to acid deposition. Simpson et al. (1985) found that acidic Adirondack streams contained fewer than half as many taxa of macroinvertebrates as did the less acidic sites, and contained few elmid beetles or mayflies.

Forms of invertebrates which live on the substrate are more sensitive to a drop in pH than those that live in the substrate. High calcium levels may counter balance the negative effects of acidification for some invertebrates.

In considering the distribution of the above species in relation to waters of varying pH no causative relationship between hydrogen ion concentration and the observed changes has been determined yet. Other factors vary with pH, *including concentrations* and availability of nutrients, bicarbonate, and various metals.

6. Fish.

The effects of acidification on fish have been widely studied and reported. As with other organisms fish may be affected by acidic conditions in a number of different ways. They may be affected both directly and indirectly by acidification of their aquatic environment, and they may respond differently during their various life history stages.

Not all species of fish respond similarly to acidification. Baker (1984) developed a figure illustrating the different sensitivities to acidification observed for a number of fish species (Figure 7). Brook trout, a fish species of importance in Adirondack pond management, is a relatively tolerant species with populations occurring in some waters at pH 4.5. Rainbow trout and lake trout on the other hand are much more sensitive to acidification. Many forage species of fish have also been shown to be very sensitive to acidic water quality (Baker 1984; Schindler et al. 1985; Johnson et al. 1987).

The mechanism for mortality of a certain fish population undoubtedly depends on the timing of acidic water quality and the sensitivity of the life stage at that time. Johnson et al. (1987) demonstrated sensitivity differences among different life stages, with the most sensitive stages being upon hatching and as early feeding fry, and the most tolerant stage being the young of the year fish. Mortality in the early life stages may result in a recruitment failure for a certain year class of fish. If this were to occur over a number of consecutive years then this fish species could be lost from the population.

A complicating factor in the discussion of toxicity is the fact that not all waters are equally as toxic, even though they may be equally as acidic. Aluminum and dissolved organic carbon are two important variables which must also be considered. Aluminum, which is abundant in most soils, is more soluble in acidic water, and increases the toxicity of the water to fish (Baker and Schofield 1982). Dissolved organic carbon, on the other hand, reacts with dissolved aluminum to reduce its toxicity to fish (Jones et al. 1986, Hutchinson and Sprague 1987). Field bioassays conducted by Colquhoun et al. (1983) and water chemistry data presented by Simonin and Dupont (1986) also show the importance of including dissolved organic carbon levels or measurements of water color in order to help determine the toxicity of a body of water. Brook trout for example have been collected from some waters with pH levels as low as 4.5 (ALSC 1987), but Johnson et al. (1987) found that in their study pH levels of 5.0 - 5.2 would be toxic to brook trout. It is evident that although two waters are equal in acidity, the water which is higher in dissolved organic carbon and therefore more highly colored will also be less toxic to fish. Bog waters are generally high in dissolved organic carbon and highly colored, and waters acidified by acidic deposition are generally very clear and low in dissolved organic carbon and therefore more toxic.

The experimental acidification of Lake 223 in Ontario provides us with valuable information on the effects of acidification on fish and fish food organisms (Schindler et al. 1985, Mills et al. 1987). Lake 223 was acidified with sulfuric acid from 1976, when the pH was 6.49 to 1981 when the pH reached 5.02, and then maintained at approximately pH 5.0 until 1983. During this period the biota and the water

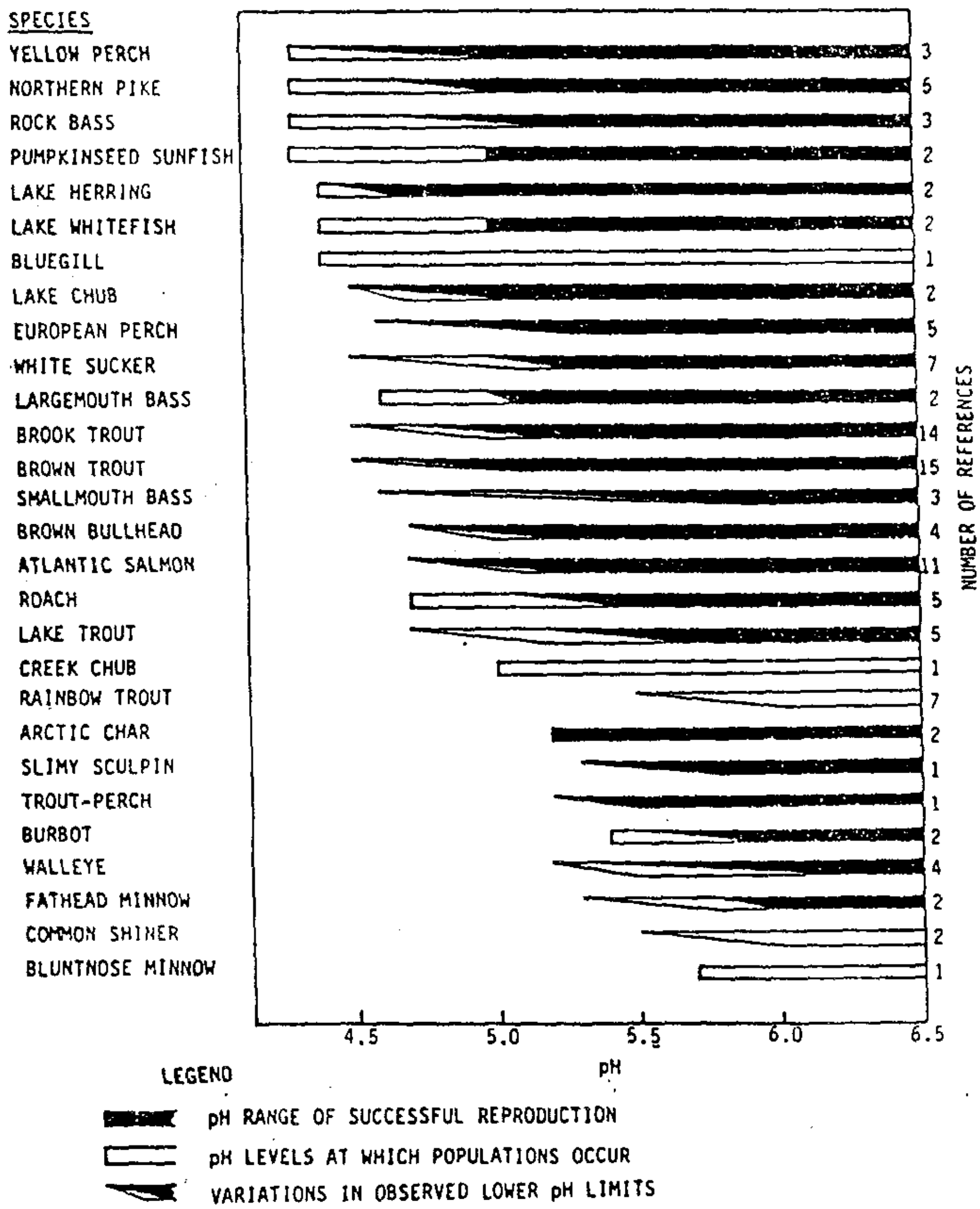


Figure 7. Initial estimates of relationship between acidity and fish response. (figure taken from Baker 1984).

chemistry were intensively monitored to document changes and interactions. Figure 8, taken from Mills et al. (1987) shows the relative changes in abundance of lake trout and their food organisms which occurred. The researchers noted that the abundance of short-lived fish species, fathead minnow and pearl dace, declined more rapidly than the longer-lived species, lake trout and white sucker. They also reported that by 1982 recruitment had ceased for all of the Lake 223 fishes. The direct effects of the experimental acidification were felt as water quality became too toxic for certain fish to survive. Indirect effects were observed in the fish when food organisms disappeared and resulted in reduced growth rates (Mills et al. 1987). The end result of such a stress as this experimental acidification would be to gradually create a fishless lake.

7. Amphibians

The effects of acidic deposition on amphibian populations are related mainly to the fact that most amphibians lay their eggs in water, and many rely on temporary ponds formed by spring rains and snowmelt. The majority of research on the responses of amphibians to these acidic conditions have therefore concentrated on the early developmental stages of a number of different species (Tome and Pough 1982). As with other organisms, not all amphibians are equally as sensitive or tolerant of acidity. Freda and Dunson (1985) reported that eggs of the Jefferson Salamander, Ambystoma jeffersonianum, could not hatch below pH 4.5, but eggs of the wood frog, Rana sylvatica, could hatch even at pH 4.25. The spotted salamander, Ambystoma maculatum, was similarly found to be very sensitive to low pH and high aluminum levels by Clark and Hall (1985), and Rana sylvatica was found to be the most tolerant.

Survival of amphibian larvae in general was not found to be affected by low pH (down to pH 4.3) or by elevated aluminum levels (Clark and Hall 1985). However Freda and Dunson (1985) found that tadpoles of two species grew significantly slower at low pH levels than at the higher pH controls. Sublethal effects of this nature may have important consequences on the survival and dynamics of an amphibian population.

Field surveys of amphibians in central Pennsylvania found that the salamander Ambystoma jeffersonianum was absent from most of the acidic ponds (Freda and Dunson 1985). The wood frog, Rana sylvatica, however was found even in ponds with the lowest pH levels. Low pH levels associated with the high dissolved organic carbon such as in bog ponds appear to be more toxic to amphibians than in clear water ponds (Clark and Hall 1985). This appears to be opposite of the effects of dissolved organic carbon in regards to acid sensitivity of fish, but additional research is needed to provide a clear explanation.

8. Wildlife

The effects of acidification on wildlife populations depends primarily on how closely associated the animals are to the acidic

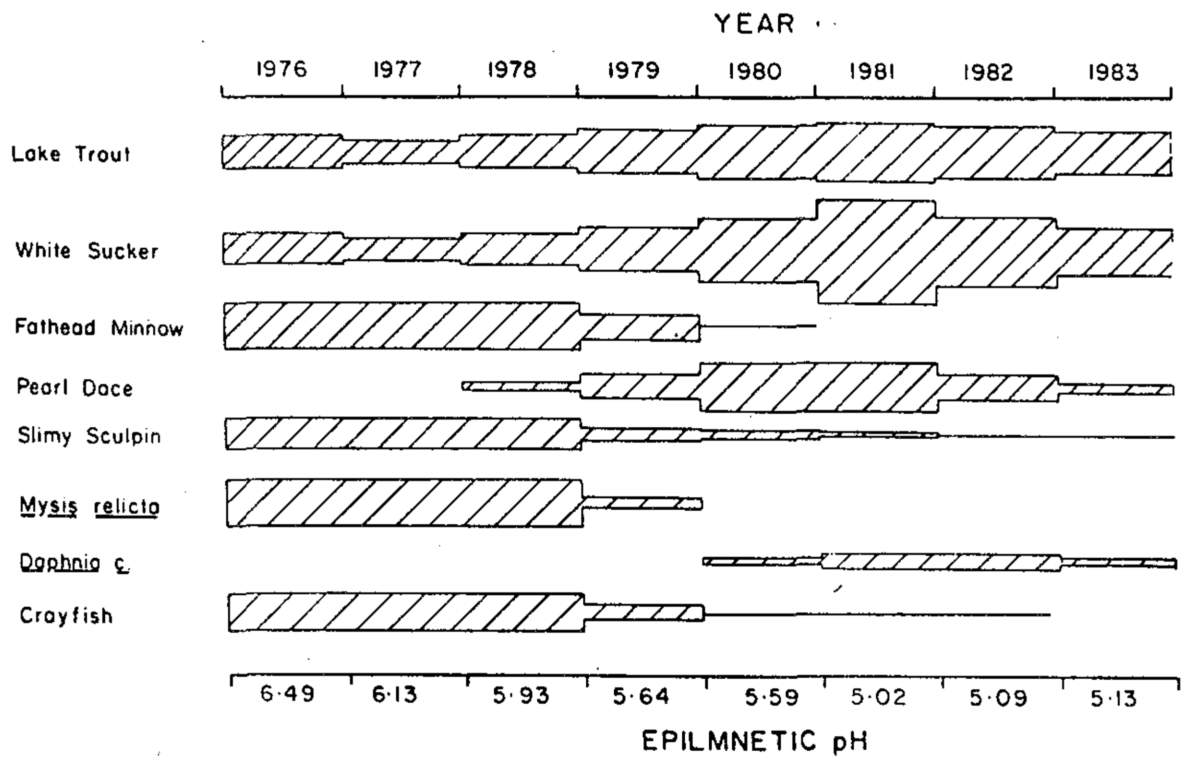


FIG. 8. Relative changes in abundance of lake trout and their food organisms in Lake 223 from 1976 to 1983. Sizes of barred areas are proportional to abundances. Sources of data are: Nero and Schindler 1983 (*Mysis relicta*), I. J. Davies, Freshwater Institute, unpublished data (crayfish *Orconectes virilis*), Malley et al. 1982 and unpublished data (*Daphnia catawba*); and this study (all fish species). (figure taken from Mills et al. 1987).

aquatic resources. If the fish populations in a lake or pond are greatly reduced or lost because of acidification, the wildlife which depend on these fish for food would also be affected. Otter, osprey and loons would have to move to other more favorable waters where fish were present. Mink may also be adversely affected by a decreased food supply. The acidification of lakes therefore represents a real loss of habitat for not just the fish, but also many wildlife species.

Hansen (1987) presented a valuable review of the impacts on waterfowl and how productivity and abundance may be reduced in acidic waters. The subject is an area of active research and public concern. Black ducks in particular have suffered a 60% decline in population over the past 30 years and at least part of this decline may have been due to acidic deposition. Competition for food with fish appears to be one complicating factor in understanding the effects of acidification on waterfowl. When fish are present in an acidic pond the fish compete directly with the ducks for the limited aquatic invertebrate food resources, but when fish are absent the aquatic invertebrate populations increase and the ducks also show better growth and productivity. DesGranges and Hunter (1987) have developed a hypothetical model of this interaction showing that the overall effect of acidification on ducks is negative. Even in a fishless pond continued acidification would lead to conditions unfavorable for duckling survival.

The nutritional value of waterfowl food resources is also affected by acidification. Mayflies, some caddisflies, molluscs, and some crustaceans are important food organisms which are very sensitive to acidification (McNicol et al. 1987). Ducks therefore become more reliant on a few insect taxa that are abundant under acidic conditions. Foods rich in calcium (eg. snails, clams, and amphipods) are important to egg-laying females and growing young and are generally intolerant to acidity (McNicol et al. 1987). Calcium deficiencies are most likely to affect the black duck, ring-necked duck, and common goldeneye (Longcore et al. 1987).

Fish eating birds such as loons, mergansers, and osprey suffer from a loss of habitat when acidic lakes become fishless. When raising their young on a fishless lake they must either rely on alternative food sources or travel to nearby lakes which do have fish. Parker et al. (1986) report that loons in the Adirondacks are unable to assess the quality and quantity of a lake's food resources prior to breeding. When nesting on fishless lakes Parker et al. (1986) observed that loons frequently only fledged one instead of two chicks, and that the adults frequently brought food to the young from nearby nonacidic lakes.

Certain other birds nesting near acidic wetlands may also be adversely affected. Blancher and McAuley (1987) reported reduced breeding success in tree swallows and reduced growth in the young of Eastern Kingbirds. A number of factors such as the rate of foraging, low food abundance, and chemical content of the eggs and young may also be related to wetland acidity.

An additional factor affecting fish eating wildlife is the increased mobilization of heavy metals in acidic environments (Wiener 1987). Mercury, cadmium and lead are more soluble in acid water and may accumulate in fish, which then may be eaten by wildlife. Methylmercury is particularly hazardous because it biomagnifies in aquatic food chains and is highly toxic to the central nervous system (Wiener 1987).

9. Function and Structure of Aquatic Ecosystems

All ecosystems have two basic functional components: autotrophic, which fixes the energy of the sun and manufactures food, and heterotrophic, which utilizes the food stored by the autotrophs (Smith 1966). Acidic deposition affects both functional components and has been discussed in detail above. Similarly the structure of an ecosystem can be broken down into abiotic, autotrophic, heterotrophic, and decomposers (Smith 1966). The interactions of the individual acidification impacts may be quite complex as they influence various levels in the ecosystem.

The first effects of acidic deposition on an ecosystem are on the abiotic components, as the sulfate and nitrous oxide anions influence the chemistry of the aquatic and terrestrial systems. It is these resulting changes which then directly and indirectly affect the biota of the system. The rate at which a certain lake responds to acidic deposition depends on many abiotic factors specific to each lake, with waters being classified as quick response, delayed response, or no response (NAS 1984). This fact results in a full range of differently impacted lakes and streams, some which have acidified relatively rapidly, and some which will never acidify, simply because of the natural buffering capacity of certain waters. Every lake and pond is different, and in New York State we have the full range from quick response to no response lakes.

In addition to these lake or watershed-specific factors, is the fact that the amount of acidic deposition falling on the watershed varies. This variable, the rate at which acid is added to the system, is the variable which man can control by reducing (or increasing) our emissions of sulfur dioxide and nitrous oxides. Several predictive models have been developed based on the assumption that if the rate of deposition changes, a variety of components affecting the ecosystem (SO_4, base cations, alkalinity) will also change (Galloway et al. 1983, Gherini et al. 1984). The effect of these changes will depend in part on how quickly different lakes or ponds can respond.

Ecosystems support a diversity of naturally occurring organisms which interact with each other and with their environment. This diversity gives a stability to the system that allows the system to respond to many different stresses (drought, disease, increased predation, etc.). Different species in the ecosystem may have unique and important roles in maintaining the stability, and many of these are still not completely understood. As discussed in sections above, an important effect of acidification is to eliminate many species of organisms which can no longer tolerate the acidic environment.

Although certain acid tolerant species may become more abundant, the resulting ecosystem has a reduced species diversity and is therefore less stable than an unacidified ecosystem. The acidified ecosystem, being less stable, is more susceptible to additional stresses, both natural and man-induced.

On a regional scale, acidification has resulted in a greater amount of habitat suitable for acid tolerant species (eg. Sphagnum) and a decreased amount of suitable habitat for acid sensitive species (mayflies, snails, dace, rainbow trout, etc.). In the Adirondacks Pfeiffer and Festa (1980) presented data showing that there are more acidic waters now than there were during the 1930's. This has undoubtedly resulted in ecosystem changes, many of which we do not fully understand.

Acidification also causes a reduction in the rates of decomposition in aquatic systems. Leaves, plants, and other organic matter accumulate on the bottom of acidic ponds and are not broken down or utilized by decomposers. This essentially removes a valuable source of nutrients from being recycled back into the system. Many of the waters sensitive to acidic deposition are already nutrient poor, and this reduced rate of decomposition further stresses the system.

10. Possible Impacts on Terrestrial Systems

The effects of acidic deposition on terrestrial systems have also been extensively studied, but few conclusive relationships have been documented. The problem is complicated by a number of factors and research is still underway studying many different aspects of the problem (NAPAP 1987). The major factor involved in many cases where plants have been negatively impacted appears to be ozone, rather than the acidity of the precipitation. Ozone is termed a secondary pollutant formed through the chemical interaction of nitrogen oxides and hydrocarbons.

Agricultural crops appear to suffer reduced yields as a result of increased levels of ozone. This impact may also be greater in areas of highly acidic rain or fog (NAPAP 1987). These impacts are complicated by normal agricultural practices of applying nitrogen fertilizers and growing leguminous crops. Both of these practices acidify the soil and are counteracted by adding agricultural limestone.

Forest decline has been a topic of major concern in many areas which receive acidic deposition. Forest decline has been reported in areas of West Germany, the Adirondacks (Scott et al. 1984, Weiss et al.1985), North Carolina (Burgess 1984), Vermont and New Hampshire (Weiss et al. 1985) and Quebec (Des Granges et al. 1987). The problem of forest decline however has occurred historically in many areas in many different species, and the causes of the decline can include disease, drought, insects, and other environmental factors (Burgess 1984). Frequently a number of factors interact to result in a decline of a certain species.

Two cases of forest decline, both in the western U.S. have been shown to be caused by ozone, possibly acting together with one or more associated oxidants (NAPAP 1987). Other cases, including the red spruce and balsam fir declines in the Adirondacks, do not have clear explanations and most likely are due to a number of causes, one of which may be high concentrations of ozone, acidic fog, or acidic deposition.

D. Fisheries and Other Societal Values

The acid deposition problem has had considerable impact on how society views our natural resources. While it must be admitted that early stories and articles which appeared in the media exaggerated the problem, it is clear that the resource has been degraded. The public's perception of this degraded environment has often resulted in a feeling of helplessness and knowledge that it is not an easily solved problem. The Federal Government's decision to further study the problem rather than seek a solution, has further discouraged many individuals.

Many of the waters which have become acidified are wilderness waters with no obvious evidence of human activity. Man is intended to be an infrequent visitor to areas classified as wilderness, and yet anthropogenic acidic deposition has intruded into these areas which society thought were protected. The result has been a real degradation of society's perception of wilderness. A real wilderness experience includes expectations of an unspoiled, natural environment, and numerous Adirondack ponds can no longer provide this experience. Regardless of the actual fishery in the wilderness waters, acidification has had an impact on how the general public perceives the natural environment.

For that segment of society which places great value on a healthy and viable fisheries resource, the losses due to acidification are even greater. Many Adirondack wilderness waters (eg. Deep Lake, Brooktrout Lake, Lake Colden and others) at one time provided well known excellent brook trout fishing. Records of large fish and healthy trout populations are recorded in books, paintings, and magazine articles of the early to mid 1900's. Today these lakes have become acidified, and any fisherman who hikes the five or more miles to these waters would find very few if any fish. Stream fisheries have been similarly impacted, and many streams which appear to provide excellent brook trout habitat are devoid of fish life because of acidification. Anglers who spend time and energy fishing these streams are met with the same disappointment as the pond angler.

Acidic deposition has in effect reduced the value of the recreational resource in impacted areas. In economic terms this has further impacts on the communities and people who rely on tourism as their source of income. Tourists may cancel their vacations or change their plans because of real or imagined effects of acidic deposition on their vacation spot.

E. DEC Policy on Acidic Deposition Control

The Department of Environmental Conservation strongly supports the reduction of air polluting emissions at their source. This represents the single most effective means of reducing the damaging effects of acidic deposition. Millions of public and private dollars have been spent to research the problem and adequate data are available to conclude that emissions must be reduced to solve the problem. The DEC strongly supported the NY State Acid Deposition Control Act of 1984 (discussed below) and has been actively working to encourage passage of similar legislation on the national level. Strong equitable acid deposition control legislation is needed on the federal level, because numerous states do not adequately control their own sources of acid deposition. The majority of the sulfur which falls on New York State comes from other states.

The treatment of selected acidic lakes with lime merely treats the symptoms of the problem and not the cause. The DEC does not therefore view lake neutralization projects as a solution to acidic deposition. Liming does however help restore and in some cases protect valuable fisheries in certain selected waters. Liming is an important tool in managing acidic lakes until the time that emissions can be reduced sufficiently to mitigate the detrimental effects of acidic deposition.

F. Reductions in Sulfur Dioxide and Nitrous Oxides Emissions in New York

In 1984 New York State passed the NY State Acid Deposition Control Act (SADCA). This legislation was one of the first meaningful actions taken in the U.S. to solve the acid deposition problem. The act directed the DEC to establish and publish regulations for the control of sulfur dioxide emissions by January 1, 1985, and a similar program was required to control oxides of nitrogen emissions.

The policy adopted to reduce sulfur dioxide emissions required that emissions be reduced to interim control target levels by 1988 (NYSDEC 1984, 1985). The final control targets are designed to ensure that New York's portion of the total deposition does not exceed its portion of the 20 Kilogram wet sulfate per hectare per year standard, which was established through the development of the acid deposition control program. As discussed in the previous section, New York State cannot solve its acidic deposition problems by itself. The SADCA will result in reduced emissions and therefore reduced sulfate deposition from New York sources. However in order to reach the desired 20 Kg wet sulfate /ha/year target it will be necessary for other states and Canadian provinces to make similar reductions in emissions.

The draft environmental impact statement for New York's policy on nitrous oxides has been released (NYSDEC 1987), but the final statement is still being prepared. This policy will not result in immediate reductions in emissions of nitrous oxides, but will require new sources to meet more stringent emissions standards. Similarly, reasonably available control technology for emissions of nitrous oxides will be required at a greater number of new sources.