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Factors Affecting Juvenile Atlantic Salmon  
Life Stages in Maine Rivers**

**A Report to the**

**Maine Atlantic Salmon Technical Advisory Committee**

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# **Water Quality Issues as Potential Limiting Factors Affecting Juvenile Atlantic Salmon Life Stages in Maine Rivers**

A Report to the Maine Atlantic Salmon Technical Advisory Committee

Ad Hoc Committee on Water Quality

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## Committee Charge:

The Signatories to the Maine Atlantic Salmon Technical Advisory Committee (TAC), in a letter to the TAC chair, requested guidance to resolve the issue whether water quality issues are a concern for the management of Atlantic salmon and worthy of future management investments. The issues of particular interest were acidification and endocrine disruptor chemicals, but other water quality issues were also to be considered. The signatories specifically requested information relative to the following three aspects:

- a) Are water quality data and on-going efforts to gather more data currently available and adequate to determine if water quality issues are a limiting factor related to the restoration of Atlantic salmon? If not, please recommend an approach so the significance of the identified water quality issues can be properly assessed.
- b) What are the relative priorities in the areas of water quality survey and inventory as compared with basic research into the impacts of the water quality factors on Atlantic salmon?
- c) Identify watersheds with the greater and lesser probabilities of vulnerability to the water quality issues identified.

In formulating a response to these questions, the committee met several times to debate the issues, review relevant reports and publications to determine the state of research on the issues, searched data archives and queried various environmental agencies to locate applicable water quality data, and prepare the written response. Although various individuals prepared certain sections of the report, all members of the committee contributed to the discussions and findings.

## Committee Findings:

The Committee believes that there is sufficient credible evidence demonstrating that several water quality issues probably are affecting restoration of Atlantic salmon populations in Maine rivers. The following issues are believed to be the most significant. Acidification and endocrine disruption are believed to be of the greatest importance to salmon restoration presently, but water temperature may also be important alone or in combination with other factors. The remaining factors lack sufficient information to determine relative importance to Atlantic salmon restoration efforts.

Acidification, from acid rain

Endocrine disrupting chemicals, from low bush blueberry applications, municipal sewage, roadside and power line applications, industrial and waste discharges, and possibly atmospheric deposition

Increased water temperature, from land-use factors, impoundments, industrial cooling water, and global climate change

Water-borne pathogens from fish culture and aquaculture activities

Fish hatchery waste

Non-pesticide organochlorines

Salt sand from winter road maintenance

Manure and biosolid compost spreading

Cumulative non-point source pollutants, including increased turbidity and sedimentation from land use factors

Chlorine and overboard discharge

A recent workshop in Canada (Cairns 2001) addressed the causes of declines in North American Atlantic salmon populations, and identified similar water quality issues (Table 1). Each of these issues is discussed in greater detail below. The response to the signatories questions a, b, and c are included in each section, except that the recommended approach to collecting new information is presented at the end of the report.

### Acidification

Acidification has been investigated in several Maine Atlantic salmon rivers periodically since 1980. Although Maine rivers are not chronically acidic, as are some rivers in Nova Scotia (Watt *et al.* 2000) and Norway (Sandøy and Langåker 2001) there are episodic declines in pH and increases in aluminum in Maine rivers that are sufficient to adversely affect sensitive life stages of salmon. Haines and Akielaszek (1984) found that pH in the Narraguagus and Machias rivers was generally between 6 and 7, but declined below 6 for brief periods during high discharge in the spring. However, several tributary streams to these rivers had pH values chronically below 6 and occasionally below 5. Total aluminum concentrations in these rivers were quite high, generally between 100 and 200 µg/L, but the aluminum was not speciated into the toxic and non-toxic forms in this study. In a later study, Haines *et al.* (1990) studied three tributary streams to the Narraguagus River. These streams had episodic declines in pH to about 5,

and inorganic monomeric aluminum (the toxic form) concentrations frequently exceeded 100 µg/L. A significant mortality of Atlantic salmon presmolts occurred during the winter of 1986-87 in Sinclair Brook, during a period when stream pH was at the lowest values measured. Beland *et al.* (1995) monitored pH in the Narraguagus River and several tributaries, and in the Pleasant River. Similar to the findings of Haines and Akielaszek (1984), pH in the Narraguagus River remained above 5 at all times, with the minimum pH measured being 5.6 to 5.7, depending on location. However, the pH of various tributary streams frequently declined below 5, with minimum pH values being as low as 4.3. The Pleasant River was more acidic than the Narraguagus, with minimum pH values in the main stem being as low as 4.1 in some years. Beland *et al.* (1995) did not measure river aluminum concentrations in their study. Most recently, the Maine Department of Environmental Protection has begun to regularly collect water samples from all Distinct Population Segment Atlantic salmon rivers in Maine for analysis of acidity chemistry parameters. These data indicate that the rivers most vulnerable to acidification are: Narraguagus, Pleasant, Machias, East Machias, and Dennys. However, current sample collection is done relatively infrequently, so that episodic changes in chemistry are not well characterized. The committee concluded that there are adequate data to determine that a risk to Atlantic salmon restoration is present and to identify the most vulnerable rivers, but that current data collection efforts are inadequate to fully characterize the risk.

Another potential source of acidity to salmon rivers in Hancock and Washington counties is the application of elemental sulfur to low bush blueberry fields to reduce soil pH. The University of Maine blueberry extension specialist (David Yarborough) currently recommends the application of elemental sulfur at the rate of 560 to 1121 kg/ha (500 to 1000 lbs/acre) to produce a soil pH of 4.2. Although most of the sulfur should be bound to the soil and not reach surface waters, there is the possibility of soil erosion or runoff from fields where sulfur is applied to ledge or other impermeable surfaces that could transport some sulfur to salmon streams, where it would reduce pH.

The toxicity of acidity to various life stages of Atlantic salmon has been the subject of numerous investigations. Although an increase in hydrogen ion (decrease in pH) in surface waters resulting from acid rain is the primary factor, toxicity is modified by water concentrations of aluminum, calcium, and dissolved organic carbon, among others (Rosseland *et al.* 2001). In addition, different life stages of salmon differ in susceptibility to various toxicity factors (Rosseland *et al.* 2001). The stages most vulnerable to acid toxicity are: embryo at fertilization, embryo at hatching, fry at swim-up and onset of exogenous feeding, and smolt. The generally accepted view is that the smolt is the most sensitive life stage, and that labile monomeric aluminum is the most important toxic factor to smolts. Kroglund and Staurnes (1999) concluded that Atlantic salmon smolts were impaired by exposure to water with pH < 6.2-6.3 and inorganic aluminum concentration as low as 15-20 µg/L, conditions that are common in Maine Atlantic salmon rivers. Recently, Magee *et al.* (2001) demonstrated that river-resident smolts from the Narraguagus River had impaired osmoregulatory ability and delayed emigration, as compared to hatchery-reared smolts. The committee believes there are adequate data describing the effects of acidification on early life stages of Atlantic salmon, but that the parr-smolt transformation and smolt out-migration stages have not been adequately investigated in the US. The committee concluded that acidification from

acid rain has a high likelihood of adversely affecting the restoration of Atlantic salmon in at least some Maine rivers, most likely through effects on parr-smolt transformation and smolt adaptation to seawater.

### Endocrine Disrupting Chemicals

Endocrine disrupting chemicals are substances that disrupt sex hormone systems in animals. The effects can occur in many life stages, and are often delayed in expression. A large number of very different chemicals have been demonstrated to have endocrine disrupting activity, including herbicides (2,4-D, atrazine), fungicides (benomyl, zineb), insecticides (DDT, methoxychlor, synthetic pyrethroids), industrial chemicals (dioxin, PCB, nonylphenols, phthalates), and trace metals (cadmium, lead, mercury). Endocrine disruptors are believed to affect smoltification in Atlantic salmon by disrupting hormone systems that facilitate the physiological processes necessary for seawater adaptation (Fairchild *et al.* 1999). In New Brunswick, Fairchild *et al.* (1999) documented a decline in returning adult Atlantic salmon in areas where a pesticide was applied for suppression of spruce budworm populations during the time of smolt out-migration. The particular pesticide used was not an endocrine disrupting compound, but the formulation included a known endocrine disruptor (4-nonylphenol) as an emulsifying agent. Exposure to 4-nonylphenol induced vitellogenin (an egg yolk protein) in Atlantic salmon smolts in the same manner as did exposure to 17  $\beta$ -estradiol (Sherry *et al.* 2001). Moore and Lower (2001) showed that exposure to atrazine, a triazine herbicide, and pentabromodiphenyl ether, a brominated fire retardant, reduced gill Na/K-ATPase activity and caused osmoregulatory disruption in Atlantic salmon smolts, as well as elevated cortisol levels, reduced survival in sea water, and reduced migratory activity. These are the same effects reported by Magee *et al.* (2001) for Narraguagus River smolts.

A variety of endocrine disrupting chemicals have been detected in Maine Atlantic salmon rivers. Dioxin, PCBs, and DDT are found in most larger rivers. PCBs have been found in fish and sediments from the Dennys River, downstream from the Eastern Surplus Superfund Site (Mierzykowski and Carr 1998). PCBs and DDT have been found in fish from the Pleasant River (Maine Department of Environmental Protection 1999). Hexazinone, a triazine herbicide structurally similar to atrazine, is commonly found in the Pleasant and Narraguagus rivers (Beland *et al.* 1995; Chizmas 1999; Chizmas 2000) as a result of application to low bush blueberry lands. Other pesticides detected in Washington County rivers in recent years include terbacil (Chizmas 2000), phosmet (Chizmas 2001), triforine (Beland *et al.* 1995), azinphos-methyl (Magee 2001), and benlate (Magee 2001). In the 1970s, DDT and its metabolites, and dieldrin were also found in the Narraguagus River (Magee 2001).

Hexazinone, similar to atrazine, has been shown to have significant endocrine activity in a cell culture assay, the E-SCREEN procedure (R. Van Beneden, University of Maine, personal communication). Other pesticides showing such activity to date include propiconazole (fungicide registered for use on low bush blueberries), methoxychlor (chlorinated hydrocarbon insecticide registered for use on low bush blueberries), and 2,4-D (triphenoxy herbicide used on residential lawns). Both nonylphenol and diethylhexyl phthalate, demonstrated endocrine disruptors, are on the U.S. Environmental Protection Agency List 1 inert ingredients ([www.epa.gov/opprd001/inerts/lists.html](http://www.epa.gov/opprd001/inerts/lists.html)), and are

incorporated into a large number of agricultural and industrial chemicals. These substances are commonly found in municipal sewage. They haven't been detected in Maine Atlantic salmon rivers, but there is no evidence that anyone has looked for them. Given the widespread occurrence of known endocrine disrupting chemicals in Maine Atlantic salmon rivers, the committee concludes that endocrine disrupting chemicals have a high probability of adversely affecting Atlantic salmon restoration.

Most of the available data on the presence of endocrine disruptors in Atlantic salmon rivers are from analysis of water samples for pesticides registered for use on low bush blueberries conducted by the Maine Board of Pesticides Control. However, many chemicals are very short-lived in the environment or are not very water soluble (hexazinone is an exception), and are thus difficult to detect in water. A recent study of spray drift by the Maine Board of Pesticides Control that used filter paper disks to collect residue (Chizmas 2001) detected phosmet at 6 of 7 locations on the Narraguagus River and 4 of 4 locations on the Pleasant River. River sediment may be a useful matrix to detect the presence of pesticide residues, but a recent analysis of Narraguagus River sediment collected above and below the area of blueberry cultivation did not detect any pesticide residue (T. Haines, U.S. Geological Survey, personal communication). There have been no systematic surveys of fish tissues for pesticide residues in Atlantic salmon rivers in Maine, nor any surveys of indicators of endocrine disruptors (e.g., vitellogenin) in fish from these rivers. Rivers located in the area where low bush blueberries are grown may be more vulnerable to this threat than others, but this is far from certain as there are other sources of pesticides and there are other classes of endocrine disrupting chemicals (see the section on non-pesticide organochlorines below). There are few studies of endocrine disruptors in Atlantic salmon in the US. Three current projects are: Endocrine Disruption in Atlantic Salmon Exposed to Pesticides, Terry Haines principal investigator; Developmental Effects of Contaminants on Salinity Preference and Seawater Survival of Atlantic Salmon: Integrating Physiology and Behavior, Stephen McCormick and Darren Lerner principal investigators; and Assessment of Impacts of Contaminants on Atlantic Salmon Smolts in Maine, Weiming Li and Stephen McCormick principal investigators. The committee concludes that there are not sufficient water quality data to ascertain the extent of exposure of Atlantic salmon to endocrine disrupting chemicals in Maine rivers, nor are there sufficient research data to ascertain the potential effects of endocrine disruptors on salmon restoration, however the available weight of evidence indicates that this factor may be important in Atlantic salmon restoration.

### Water Temperature

Maine rivers lie near the southern extent of the Atlantic salmon's range in North America, and are vulnerable to elevated water temperature regimes. Contributing factors include improper or unregulated land use practices, impoundment of free-flowing reaches (where applicable), discharge of industrial processing or cooling water, and broad climatic changes. Relatively minor increases in water temperature may diminish habitat suitability for adult and juvenile salmon, lead to sub-lethal or lethal physiological responses, and have a profound negative effect on the production potential of a river or stream. Preliminary results from research conducted by the U. S. Geological Survey, in

cooperation with the Maine Atlantic Salmon Commission, indicate that the timing and magnitude of seasonal river flow, the occurrence and duration of river ice, and the seasonal water-content of coastal snow pack are showing systematic trends over time. Spring runoff has become earlier, water content in snow pack for March and April has decreased, and the duration of river ice has become shorter (Robert Dudley, U.S. Geological Survey, personal communication, 2002). It appears that large lakes in the Northeast are covered by ice for a shorter time in the winter as compared to the earliest records (around 1900). The ice-on date for these large lakes (e.g. Moosehead Lake) is about a week later and ice-off dates occur about a week earlier than what had been observed historically.

Recent data released by the Climate Monitoring Branch of the National Climatic Data Center show that the 2000-2001 winter was the warmest on record for the United States. The agency also reported that worldwide average temperatures for the last 100 years have increased. In addition, the 10 warmest individual years on record clustered in the 1990's, indicating a global warming trend. Atlantic salmon typically spawn in water temperatures ranging from 4-10°C and successful egg incubation generally occurs below 8°C (Danie *et al.* 1984). Optimal growth of juvenile salmon occurs when water temperature is between 15 and 19°C with normal feeding patterns being disrupted when temperatures exceed 22.5°C (Danie *et al.* 1984). Lethal temperatures for juvenile Atlantic salmon are 27.8°C at 7 days exposure, 29.5°C at 1000 minutes, 31.1°C at 100 minutes and 32.9°C at 10 minutes (Elliot 1991). Tolerances for adults have not been adequately studied, however, based on historical observations by Huntsman (1942), and more recent observations by fishery scientists at adult collection facilities such as on the lower Penobscot River, adult tolerances may be 2-3 °C lower than juveniles.

Recent historical water temperature data (last 10 years) exist to some extent for most Maine salmon rivers, with the Penobscot and Narraguagus Rivers having historical temperature data dating back to the mid 1950's. To date the majority of these data are in scattered reports or still in files waiting to be assembled. The Downeast Rivers have an ongoing monitoring program that was instituted by the Maine Atlantic Salmon Commission and U.S. Fish and Wildlife Service in the early 1990's. The recent availability of inexpensive, user friendly digital temperature loggers and powerful desktop computers and software has greatly simplified temperature data collection and assimilation. Water temperature monitoring in Maine salmon rivers is no longer solely dependent upon Federal and State agency programs. Indian tribes (e.g. Penobscot Indian Nation), private conservation groups (e.g. Atlantic Salmon Federation), and local watershed councils (e.g. Sheepscot Valley Conservation Association) have purchased their own loggers and currently carry out monitoring programs of their own. In most instances these data are readily available, of high quality, and with some guidance, can be easily incorporated into larger data sets.

Currently the Downeast salmon rivers (Narraguagus, Pleasant, Machias, East Machias, Dennys) have an on-going monitoring program that was instituted by the Maine Atlantic Salmon Commission and the U.S. Fish and Wildlife Service in the early 1990's. The Kennebec, Androscoggin, Sheepscot, and Ducktrap rivers, along with Cove Brook, also have had recent water temperature monitoring activity (generally late 1990's to the present), much of which has been carried out by local watershed councils.

In January 2002, the Atlantic Salmon Commission produced a database with the intent of assimilating available temperature data into one central hub. This data base allows the user to quickly access large sets of temperature data, referenced by a set of user-defined criteria such as drainage, site, date(s), etc. in a more powerful and simpler way than previously. Metadata for historical data sets are included, while new/current logger deployments will be carried out under a standard protocol being developed by the Commission. In the end, this database will greatly facilitate intra- and inter-river comparisons of water temperatures and long-term trend analysis for Maine salmon rivers.

The committee concludes that water temperature may be an important limiting factor for Atlantic salmon rearing habitat in Maine rivers, and the possibility exists that temperature may become even more important in the future. In order to determine if global climate change is responsible for this effect, very long-term temperature records of very high precision will be required.

### Water-borne Fish Pathogens

Links among water quality, stress, immunosuppression, pathogen prevalence, and disease susceptibility are well established (Anderson 1990, Coutant 1998). In addition, these factors are compounded in high density rearing conditions that can be common in hatchery or aquaculture programs. Accordingly, the state's Departments of Inland Fisheries and Wildlife (MDIFW) and Marine Resources (DMR) have long enacted a salmonid health-monitoring program for exotic and endemic infectious salmonid pathogens.

The current salmonid fish health inspection regulations (09-137 Code of Maine Rules Chapter 2.03-A) identifies exotic and endemic infectious pathogens of regulatory concern, prohibits the transfer of live salmonids or gametes among culture facilities until the fish are tested and certified pathogen free, outlaws the sale of clinically ill fish, outlines a standardized annual testing and monitoring protocol for all salmonids in public and private facilities, requires that fish taken from the wild be isolated until inspected for diseases, and upholds stringent regulations for salmonid importation into the state. This ruling also outlines a standard protocol for action in the case of a confirmed disease outbreak and authorizes the existence of the Maine Fish Health Technical Committee.

Although Maine has taken the potential impacts that introduced salmonid diseases can inflict upon wild and hatchery-reared stocks quite seriously, there is no standard monitoring protocol for wild salmonid populations or other fish species. Last year, the National Marine Fisheries Service (S. McLean – principle investigator) screened several lots of anadromous alewives, American shad and American eels from the Gulf of Maine for Infectious Salmon Anemia virus (ISA). Their results prompted a continuation of the disease-screening program for shad and alewives this coming year (Danner, G. R. MDIFW, personal communication). However, there is no indication whether this will be a continuing program after the 2002 season. Additionally, the Fish Health Laboratory (MDIFW) does test any disease suspect brought to its attention by either public or private parties and control measures are enacted if necessary. There is no current or routine disease monitoring protocol for any wild inland fish population in Maine. The multi-agency cooperative Aquatic Invasive Species Task Force authorized by the Maine Legislature in 2001 has included some freshwater and marine fish and shellfish pathogens

on the statewide list of aquatic invasive species. It is too soon to know what, if any, regulatory effects or monitoring protocols this will bring about.

Fish health can be an important component in long-term fisheries management and Atlantic salmon restoration efforts. Considering the potentially stressful conditions that poor or deteriorating water quality can inflict upon all fishes, we can not rule out the associated factors of immunosuppression and disease susceptibility as contributing to overall population health and the apparent difficulties in salmon recovery. There is strong evidence that the salmonid pathogens *Renibacterium salmoninarum* (Bacterial Kidney Disease, BKD) and Infectious Pancreatic Necrosis virus (IPN), both endemic in Maine, are more virulent in softer water conditions (Danner, G. R. MDIFW, personal communication). Initiating a strong fish health inspection program for inland fish populations will provide further answers regarding overall population health, indicate population stress levels, and will alert fisheries biologists to contributing factors in the difficulties of Atlantic salmon recovery.

The committee concludes that fish pathogens may be a significant factor affecting recovery of Atlantic salmon populations in rivers with hatcheries in the watershed or with sea net pens near their mouths.

### Fish Hatchery Waste

Within the range of the Distinct Population Segment there are five<sup>1</sup> salmonid hatcheries or production facilities, of which four are Atlantic salmon hatcheries used for aquaculture or salmon restoration purposes. Three of these are within rivers that have functioning, remnant wild Atlantic salmon populations (Baum 1997; King *et. al.* 1999) and are listed under the federal Endangered Species Act. The Deblois hatchery on the Pleasant River and the Gardener Lake Hatchery on the East Machias river are both aquaculture owned or leased facilities raising salmon smolts for the aquaculture industry. The Palermo fish rearing facility on the Sheepscot River is a state owned fish hatchery raising brown trout and splake (Lake Trout/Brook Trout cross) for the Maine Department of Inland Fisheries and Wildlife (MDIFW) sportfish stocking program. Both Green Lake National Fish Hatchery and Craig Brook National Fish Hatchery are federally owned Atlantic salmon hatcheries that are within the range of the DPS, but are not located within watersheds identified as having remnant wild Atlantic salmon populations.

All five of these hatcheries discharge wastewater into adjacent or nearby rivers, lakes, or streams with little or no treatment other than settling ponds to separate out solids. The Environmental Protection Agency has identified eleven pollutants of concern that are commonly associated with hatchery effluents. They include: solids, nitrogen, phosphorous, organic compounds and BOD, salts and trace elements, odors and volatile compounds, pathogens (human and fish), pesticides, antibiotics, other chemicals and non-native species and escapement (*EPA power point presentation, unpublished data*). From a regulatory point of view, wastewater discharge limits tend to focus on phosphorous and BOD. In Maine, escapement of non-North American strain Atlantic salmon, often raised

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\* . There are two privately owned satellite salmon rearing stations within the DPS. The Pleasant River Hatchery on the Pleasant River in Columbia Falls, and the Union River Hatchery on the Union River in Ellsworth both raise Atlantic salmon from the egg to non-feeding fry stage. Since they are not feeding fish, neither facility anticipates discharge of pollutants and therefore are not required to obtain a state discharge permit.

by the aquaculture industry, was identified as a threat to endangered wild Atlantic salmon populations in the Final Rule (50 CFR Part 224).

Until recently, the Environmental Protection Agency has not administered limitations and standards for freshwater hatchery discharge. But with the dramatic growth of the aquaculture industry and the inconsistencies between state regulatory agencies, EPA has assembled a task force to address wastewater discharge concerns and ultimately produce national discharge standards for all commercial and public aquaculture operations (EPA-821-F-00-002). These standards will be incorporated into the National Permit Discharge Elimination System (NPDES) that was delegated to the state of Maine in January 2001. At this time EPA anticipates that it will develop a proposed rule by June 2002 and consummate new regulations by 2004. The State of Maine DEP initiated new discharge restrictions in 1999 and will issue five-year licenses with a compliance schedule to hatcheries in 2002. Maine's new restrictions are more restrictive than those proposed by EPA. These restrictions will require facilities to limit the use of certain chemicals, and develop standards that will reduce the nutrient pollutant load, which includes a reduction of phosphorous discharge by up to 90%. The new restrictions set forth by the state will be based on the states waters classification standards set by Maine DEP.

### Non-pesticide Organochlorines

The general class of chemical compounds known as organochlorines (or chlorinated organics) is composed of hundreds of chemicals, many of which are structurally complex, and all of which have at least one chlorine atom and one "benzene ring" (C<sub>6</sub>H<sub>6</sub>). Many organochlorines of industrial origin have yet to be fully identified or chemically speciated. Excluding organochlorine pesticides (discussed elsewhere in this report), the most widely recognized and studied contaminant groups within this class are dioxins, furans, and planar polychlorinated biphenyls (PCB).

A variety of natural processes, such as forest fires, can generate small amounts of a few of these compounds (e.g., dioxins) that can end up in surface waters. Surface waters may also receive dioxins and dioxin-like compounds through atmospheric deposition and trace discharges from municipal sewage treatment plants. However, many of these compounds, at least in Maine waters, originate from the paper-making industry, from textile mill and tannery effluent, from landfill leachate, or from other point source and hazardous waste disposal sites. Organochlorines have a tendency toward high environmental persistence, warranting an examination of historical legacies (e.g. sediment repositories) as well as direct discharges, when assessing potential impacts to aquatic life migrating through contaminated water or inhabiting contaminated habitats or substrates.

Individual compounds, and even isomers of the same compound, appear to have substantially different toxicities to aquatic life and humans. Generally, the toxicity of these compounds in water or sediment, as well as the total contaminant burden present in an exposed organism's tissue, is calculated and expressed as a weighted summation, termed the "Toxicity Equivalent" (TEQ) value.

A scan of relevant literature indicates that dioxins, furans, and PCBs can impart sublethal and lethal physiological effects to exposed fish in at least three ways:

1. Through direct/acute toxicity to the exposed organism.
2. Through chronic bioaccumulation in fatty tissue (primarily).
3. Through maternal transfer to eggs of exposed gravid females.

Documented effects of exposure by one or more of these routes, including several species of salmonids, include general physiological and endocrine dysfunction, decreased egg viability and fry survival (Walker and Peterson 1994; Zabel *et al.* 1995), abnormal gene expression, genetic fragmentation (genotoxicity), and, in extreme cases, direct mortality (Sijm and Opperhuizen 1996). Notably, few studies have involved anadromous Atlantic salmon. Preliminary results from one relevant study, however, indicate that parr with PCB burdens above a certain threshold exhibited amplified gene expression at certain chromosomes (J. Kocik, personal communication). This amplified expression was increased by 100 fold or more in Atlantic salmon parr exposed to PCBs in a Massachusetts river. Although this work was not intended to determine the ultimate effects of amplified expression on the affected organism, such investigation would seem to represent the next logical step. The National Marine Fisheries Service intends to initiate a similar study in 2002 using parr from affected and unaffected sites on the Dennys River.

Within the geographic boundary of the currently-established DPS for Maine Atlantic salmon, and excepting the Eastern Surplus Superfund site on the Dennys River discussed in an earlier section of this report, virtually all information available on these contaminants in water or aquatic life results from studies on the Penobscot River. Most of this information has either been collected by the Maine Department of Environmental Protection (Mower 2000), by the Penobscot Indian Nation, cooperatively between the Maine DEP and Penobscot Indian Nation (e.g., Surface Waters Ambient Toxic (SWAT) Monitoring Program), the U.S. Geological Survey (Orazio *et al.* 2001), or by applicants for wastewater discharge and hydropower operating licenses. The current database is quite extensive. Notably, however, these studies have focused almost entirely on determining existing burdens in resident species. The primary purposes of these studies have been to determine the contribution of industrial wastewater discharge to existing fish tissue burdens, establish fish consumption guidelines for human consumers, and to identify the potential contaminant burden to higher trophic level wildlife consumers such as the bald eagle (Welch 1994; Mierzykowski and Carr 2002). Thus, beyond the fact that anadromous Atlantic salmon have not been included in these bioaccumulation assessments on the Penobscot, the data for resident species does not substantively address either the exposure route or the direct effects of exposure to the organism itself. Conversely, these data do provide insight into where particular discharges or repositories may represent a problem with respect to the various freshwater life stages of Atlantic salmon in the Penobscot.

Finally, the committee recognizes that there are literally dozens of reports, textbooks and other media that speak in great detail to the issues summarized in this section. However, it was decided to simply highlight this toxicological issue, and provide a list of “starter” references for possible further investigation, whether that be directly on

the part of the Signatories or as a future extension of this working group's activity. These references include: Colborn and Clement (1992), Eisler (1986), Eisler and Belisle (1996), Servos *et al.* (1996), Turoski (1998), and U.S. EPA (1993).

### Salt Sand From Winter Road Maintenance

A mixture of salt (NaCl) and sand is spread on Maine roads during the winter to keep the roads ice-free and to provide traction. In the spring, rain and melting snow wash the salt and the sand onto the road sides and sometimes into surface waters. In addition, road salt solutions infiltrate into the ground. There have been incidents of public and private wells having been contaminated by road salt. Sand that remains on the roads after the end of the season is generally swept off the roadways onto the shoulders. Sometimes this sand is collected and disposed of as inert fill. Due to light contamination with heavy metals and oils from the road application, the sand is not recycled for additional road applications.

Sand that washes into streams and rivers can result in turbidity problems and habitat embeddedness. This is especially noticeable in the Sheepscot River because it has a higher road density and more stream crossings than the other salmon rivers. The Sheepscot River crossings with the most noticeable sand impacts are Rte. 126, Rte. 105, and Rte. 17 on the main stem, and the Howe Road, Rte. 3 and Weeks Mills crossings on the West Branch (Halsted, personal communication). Maine Department of Transportation (MDOT) installed settling basins at the end of the roadside ditches to collect sand on the Rte. 17 and Rte 105 crossings. However, MDOT does not clean out the basins. The basins are either cleaned out by town road crews or by volunteers associated with the watershed council, or they are not maintained (Halsted, personal communication). Route 105 has a settling basin that is not maintained. This settling basin overflowed in the winter of 2000-2001 and sand entered the Sheepscot River.

MDOT is planning to phase out their old salt sand maintenance program while phasing in a new "Salt Priority" program. Essentially, rock salt mixed with a little calcium chloride is applied to the roads in advance of a storm. This mix prevents snow and ice from adhering to the roads, making plowing easier. Almost all snow can be removed from the road since it does not stick to the road. The salt also prevents the formation of glare ice or "white ice" from packed snow. The greater snow removal efficiency and the prevention of ice formation result in significant traffic safety improvements. Pilot projects in Maine show that sand applications can be reduced by 80% (Piccard, personal communication). MDOT is presently in the second year of a three-year transition for this program. Winter maintenance of Route 3 and 17 in the Sheepscot watershed already uses a Salt Priority protocol. Once the state-wide transition is completed, sand should be much less of a problem for the salmon rivers. Salt is generally only a problem as a groundwater contaminant or for lakes. Occasionally, lakes will develop a mixolimnion due to the formation of a high density salt layer. In rivers and streams, however, road salt is not known to be a problem for fish.

## Manure and Biosolid Compost Spreading

The spreading of composted manure on agricultural land, or the spreading of composted biosolids on forest or agricultural land are regulated by different agencies in Maine. Manure spreading is regulated by the Maine Department of Agriculture. Most spreading does not require an actual permit as long as it is done according to best management practices. Larger farms with more than 50 cows or landowners who import biosolids from other off-site sources are required to have Nutrient Management Plans (Pennell, personal communication). These plans are technical documents that are generally written by the USDA Natural Resources Conservation Service. Nutrient Management Plans require soil testing to determine the soil nutrient needs, soil type and depth, and runoff potential. Compost is tested for nutrient levels and an appropriate spreading rate is calculated. Buffers of 100 feet are maintained between the compost and major surface waters (lakes and stream). Smaller buffers are allowed along small drainages. Generally these buffers are 25-50 feet wide depending on the nature of the drainage. Buffers of 300 feet are required between spreading sites and wells. Fish hatchery wastes have been classified as an agricultural product and can be spread as “manure.” Except for special waivers, no manure is spread from December 15 to March 15.

Spreading of composted biosolids is regulated by the Maine Department of Environmental Protection (MDEP). Maine is recognized as a leader in the beneficial application of biosolids (Goldstein 2000). Biosolids are the organic products from municipal or commercial sources that may be suitable for agricultural applications. Types of biosolids that might qualify for beneficial use permits include composted municipal sewage, food waste, wood fiber waste, fish processing waste, blueberry wash water, dredge materials, dewatered septage, and ash from wood fuels. Like the agricultural Nutrient Management Plans, the application protocol for biosolids is site-specific. The soils and composted materials are tested to calculate an appropriate spreading rate. Both minimum “setbacks” and “buffers” are maintained next to surface water and wells. The minimum setback for compost spreading near homes and domestic water supply wells is 300 feet. The minimum setback is 100 feet for major surface water bodies (lakes, rivers, and perennial streams) and is 35 feet for intermittent streams and ditches. The vegetated buffer may exceed the minimum setbacks depending on the kind of land cover present, slopes, soil type, etc. (Haffner, personal communication). As long as the compost spreading is done according to state regulations and with the appropriate oversight, there should be minimal potential for deleterious effects on water quality.

## Cumulative Non-Point Source Pollution Problems

All of the Maine salmon rivers flow through small developed areas (e.g., small town centers) and larger undeveloped areas supporting a variety of rural land uses. These multi-use rural areas and developed zone result in varying amounts of non-point source pollution to salmon rivers. Some of those disturbances and inputs have been discussed above (e.g., pesticides, salt sand, nutrients). Sometimes there is no identifiable single source, but water quality problems seem to be due to a cumulative effect of many non-point sources in the watershed. The Downeast river watersheds have very low human

population density. The greatest development density occurs on the coast and along US Route 1 and Route 1A. The rural lands above Route 1/1A are less developed and tend to be managed for forest products and blueberries. Forests and blueberry fields generally have good ground cover. However, commercial and recreational access to these rural lands has resulted in a high density of small, seasonal land management roads. These roads are often 8-12 feet wide with a gravel surface. Some of the forestry tote roads are major 2-lane conveyances. These forest management and blueberry field roads are not generally maintained in the winter, except that some are used as snowmobile or ATV trails. In general, these seasonal roads are prone to NPS pollution due to erosion on the road surfaces, roadside ditches, or bank erosion at stream crossings. Of the NPS pollution sites identified in the Project SHARE database, most are eroding roads or stream crossings. These cause localized water quality and embeddedness problems in the salmon rivers.

The Sheepscot River has the poorest water quality of any of the Maine salmon rivers. Large reaches of river turn cloudy in the spring or fall (TSS range 1-47 mg/l and turbidity 0-4.9 NTU, Whiting 2001). The turbidity may last for 4-6 weeks during the spring melt period (as it did in the spring of 2001) and again during individual large runoff events in the fall. The cloudiness of the water may have a daily cycle in the spring, being slightly turbid in the morning and cloudiest in the late afternoon (personal observation by M. Whiting). This 24-hour cycle seems to follow daily melt cycles. Some of this suspended material is salt sand that is washed into the river during spring rains. In the fall, some of this material is resuspended. The Sheepscot River has the highest density of year-round roads of any of the salmon rivers. In a review of the effects of sediment loads and turbidity on fish, Newcomb and Jensen (1996) conclude that more than 6 days of exposure to TSS greater than 10 mg/l is a moderate stress for juvenile and adult salmonids. A single day of exposure to TSS in excess of 50 mg/l is also a moderate stress.

Cove Brook has severe sediment problems (TSS range 1-100 mg/l and turbidity 0-40 NTU). Like the Sheepscot River, the turbidity conditions persisted for weeks in the spring of 2001. Long duration high turbidity events did not occur in the spring of 2002, possibly because of the early thaw (the winter of 2001-2002 was the warmest on record, Cornell News, 2002). The high flow period occurred in early to mid-March when the ground was still frozen. Unlike the Sheepscot River, the turbidity problem in Cove Brook seems to be related to failing stream banks and not land use (Corr, unpublished data). According to Newcomb and Jensen (1996) several hours of exposure to TSS greater than 55 mg/l is a moderate stress level for salmonids. There is other evidence of NPS problems in the Sheepscot River. This river has long reaches where summer daytime temperatures are in excess of 22 degrees C (SVCA, unpublished data) and where dissolved oxygen (DO) levels drop below 7 mg/L (Abello, unpublished data). For instance, at the Dyer River sample site in the upper estuary, the number of days where DO is less than 7 mg/L ranges from 33% to 100% of the sample dates since 1994. For the West Branch of the Sheepscot at Route 105 in Whitefield, the number of sample days where DO is less than 7 mg/L ranges from 30-80%. In general, some smaller tributaries are more susceptible to these effects than the river main stems. Consequently, the West Branch of the Sheepscot River is more vulnerable than the main stem.

Occasionally, bacteria monitoring data show that high bacteria counts coincide with low DO values (Abello, unpublished data). For instance, on Meadow Brook (a tributary to the West Branch of the Sheepscot) below a dairy farm the geometric means for *E. coli* range from 64.8-279 colonies per 100 ml and the number of days with DO values below 7 mg/L ranges from 0-100% of the time for four years sampled. At other times the bacteria counts have less obvious associations with land uses.

Maine has a water quality classification program to prevent human activities from degrading water quality. The designations for freshwater rivers and streams is AA, A, B, and C. Class AA is the highest and C is the lowest water quality. The lower Sheepscot River from Route 17 to the estuary and the West Branch of the Sheepscot River are designated Class AA. The Sheepscot River north of Route 17 (Montville) and the tributaries to the Sheepscot are Class B. Class AA water quality parameters should be “as naturally occurs” (i.e., there should be no noticeable anthropogenic effect). Maine’s water quality standard for Class B waters state that the *E. coli* geometric means must be less than 64, and that the instantaneous values must be less than 427 colonies per 100 mL, and DO values must be at least 75% saturation or 7 mg/L. Many tributaries and many reaches on the West Branch do not meet Class B standards.

As noted earlier in this report, Atlantic salmon are stressed whenever water temperatures are above 22.5 C. If the high water temperature exposure lasts for more than a few hours there is a deterioration of body condition (Elliot, 1991). Summer oxygen levels below 6 mg/L are not suitable for salmonids. While *E. coli* are probably not pathogenic for healthy fish, high bacteria numbers are indicative of suburban and agricultural runoff and/or failed septic systems. Taken together, these indicate a cumulative NPS impact on the river, including nutrient laden runoff, significant biological oxygen demand, and loss of riparian areas. Although NPS pollution issues are noticeable on all the salmon rivers, the cumulative impact seems to be most evident in the Sheepscot River watershed.

#### Chlorine and Overboard Discharges

An overboard discharge (OBD) is an alternative wastewater treatment system for sites where municipal sewer connection is not possible and where a traditional septic system is not feasible. The simplest kind of overboard discharge (OBD) is a holding tank with a chlorinator for the overflow pipe. This “Primary” type of treatment is common on boats and is sometimes found on land systems. A more sophisticated type of OBD is an “activated sludge” or “mechanical” process where a tank full of wastewater is aerated and mechanically mixed. It is called “activated” sludge because the aerobic conditions result in rich assemblages of micro-organisms and protozoa. This type of OBD is effective at reducing the biological oxygen demand of the wastewater. The wastewater is discharged through a chlorination unit. The third kind of OBD is a “sand filter.” It has a septic tank with a sand filter to digest the organic materials. Like a typical septic system, the sand filter OBD provides the best overall treatment of the organic waste. Treated water is collected below the sand filter and the discharge is put through a chlorinator before it goes into receiving waters.

Almost all OBD’s use chlorine tablets (calcium hypochlorite) in the chlorinator unit. Chlorine is dissolved and is picked up by the wastewater as it flows past the tablets. The dose is thus inexact, but the system is designed to be conservative and

provides more than enough disinfectant (at least 1.0 mg/L residual chlorine). Typically, there is either too much chlorine (say from a fresh tablet) or no chlorine at all (the owner did not replace the tablet). Cherryfield is located on the Narraguagus River. Approximately 50% of the inspections of Cherryfield OBD's indicate that owners were not in compliance with their license (generally no tablet or too many tablets). Thus, chlorinators tend to cause the formation of localized dead zones in streams, due to excess chlorine when there are tablets in the system or due to bacteria and high oxygen demand when the tablets are depleted. In 1987, Maine enacted the Overboard Discharge Law. This prohibited any new non-municipal sanitary wastewater discharges to Maine waters. Furthermore, any existing OBD's with an expiring license must be converted to a better system if one is feasible.

There are 37 OBD units in Cherryfield between the Route 1A bridge and the "upper bridge," a distance of about 0.8 miles. All of these systems are the sand filter type. This situation along the Narraguagus River is unique among the DPS salmon rivers; no other river has such a concentration of OBD's. Calcium hypochlorite forms hypochlorous acid (HOCl) and the hypochlorite ion (OCl-) when dissolved in water. Together these compounds are known as "free residual chlorine" and are the active disinfectants. A similar compound, sodium hypochlorite, is the familiar household liquid bleach. Free residual chlorine is very toxic, lethal doses are measured in ppb. The EPA recommended maximum concentration for the maintenance of fish and aquatic life is 10 ppb. Young fish are the most vulnerable life stage to chlorine compounds. Trout fry will die after exposure to 6 ppb chlorine in 48 hours (EPA, 1976). Low pH and high temperatures increase the toxicity of chlorine. Chlorine reacts with decomposing organic matter to form trihalomethanes. Chlorine also reacts with phenolic compounds to form chlorophenols and with ammonia to form chloramines. The active forms of chlorine also break down quickly when exposed to sun light and organic matter. Free residual chlorine does not persist in a stream environment.

The potential effects of chlorine compounds on Atlantic salmon are unknown. We do know that chlorine compounds are poisonous, strong oxidants, and powerful irritants. Some are carcinogenic (such as the trihalomethanes and dioxin). The effects of these compounds on salmon olfactory senses and homing behavior have not been studied. The density of OBD's in Cherryfield, however, should be a matter of concern to Narraguagus River salmon restoration efforts. Many of these OBD systems are probably designed to treat 300 gallons per day. With 35-39 systems discharging into the river in a reach less than one mile long, there is potentially almost 12,000 gallons of treated effluent entering the river each day.

### Recommended Approach

Firstly, the committee recommends that all available water quality data on Maine Atlantic salmon rivers be assembled into a regularly-updated computerized database. Dozens of reports, publications, and data files containing valuable water chemistry information were located by the committee, but it was extremely difficult and time-consuming to adequately collate and review these data. A centralized, computer-searchable data repository is needed to facilitate water quality record-keeping and to ensure that data collection and analyses are not duplicated.

*Acidification:* an intensive, long-term (several years, at least) water chemistry monitoring program should be initiated on one or two representative DPS rivers. The Narraguagus River is suggested as one possible site, because of the large amount of data available for this river. Sites should be located above and below blueberry growing areas, to determine if sulfur application for soil pH control affects stream acidity. Water samples should be collected with an automated system that is tied to a discharge monitoring site, so that more frequent samples can be collected during times of increased stream flow. Water samples should be analyzed for pH, acid neutralizing capacity, inorganic monomeric aluminum, dissolved organic carbon, and major cations and anions. Only by measuring the complete suite of chemical parameters will it be possible to interpret the implications of changes in acidity to Atlantic salmon. An automated water chemistry monitor can be used to supplement these collections, but not replace them. Research activities should focus on the effects of acidity parameters on the parr-smolt transformation, and smolt adaptation to seawater.

*Endocrine Disruptors:* because of the large number of chemicals that may function as endocrine disruptors, and the difficulty in analyzing for short half-life compounds in a variety of matrices, it isn't reasonable to attempt a comprehensive contaminant monitoring program. However, it would be possible to collect stream-resident fish (e.g., white sucker) from virtually all present DPS rivers and potential Atlantic salmon spawning streams, and analyze them for tissue residues and biochemical factors indicative of exposure to endocrine disrupting chemicals. Such factors could include: vitellogenin, 17  $\beta$ -estradiol, testosterone, other steroid hormones, and P450 enzymes (e.g., CYP19, CYP2C, CYP1A). Locations where stream-resident species indicate the potential for exposure to endocrine disruptors could then be further investigated to determine if Atlantic salmon smolts show any evidence of endocrine disruption.

*Temperature:* because of the low cost and low maintenance associated with digital data loggers, and the high quality data that they are capable of producing, it is recommended that monitoring continue on rivers where it exists at least at the current level of effort. When possible, monitoring activities should be shifted to well-organized groups (NGO's, watershed council's, Indian tribes, etc.) with guidance from the Maine Atlantic Salmon Commission (ASC) and with an understanding that data will be included in the ASC temperature database. These compiled data would then be available to all groups interested in the restoration of Atlantic salmon in Maine. Effort needs to be put into locating, assimilating, and importing historical data into the temperature database so that trends in river temperature can be investigated. Some effort also needs to go toward educating people on how to access and use the temperature database.

*Water-borne fish pathogens:* a pathogen monitoring program for resident fish species of the DPS salmon rivers should be instituted. Little is known of infectibility or endemism of salmon pathogens in other freshwater species. A preliminary screening of a 30 – 60 multi-species sample from each salmon river should be undertaken. Similar samples should be tested annually for both endemic and exotic salmon pathogens. These data

would not only provide estimates of salmon pathogen presence within these systems, they would also provide an indication of overall fish community health and stress levels.

*Fish Hatchery Wastes:* encourage the incorporation of fish hatcheries into the NPDES licensing system. Encourage DEP to follow up with inspections and enforce compliance with NPDES standards.

*Non-Pesticide Organochlorines:* The existing information on routes of exposure and range of effects documented for other species, considered in the temporal and spatial context of Atlantic salmon life stages in freshwater, suggests that exposure of juvenile stages to organochlorine-contaminated water, sediments, or food supply, and exposure of gravid adults (and thus potentially their eggs) to contaminated water during upstream migration, would be the likely mechanisms potentially leading to detrimental effects on physiological or genetic function, or egg viability. Thus, on rivers where these contaminants are known to occur (e.g. Penobscot, Kennebec, St. Croix, or Dennys River below the Superfund site), the Committee recommends focusing future investigations on these mechanisms of exposure, uptake, and effect.

*Salt Sand:* the Salt Priority program may eliminate sand discharges to the salmon rivers from state roads. There must be money and training (from MDOT?) to help towns to make the transition. This means new equipment for town road crews. Also, since the low-sand maintenance program is not a no-sand program, settling basins may need to be built and maintained on all major road crossings. Volunteers may be needed to clean out these settling basins annually in the spring.

*Manure and Compost Spreading:* there may be no problem as long as organic wastes are applied according to state programs. If not, there must be more emphasis on enforcement and follow-up.

*Cumulative NPS Problems:* this is the whole purpose of the watershed councils. Continue funding the watershed councils. They would be more effective with some paid staff.

*Chlorine and OBD's:* there is already a state program to replace OBD's and it has adequate funding, the problem is that up-dating or improving a legal system is optional and there is generally some cost to the owner (even though the state pays most of the cost, generally 90% of a private home system). Some funds to pay the owner's part of the replacement system might get these OBD's out of the river quickly.

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Table 1. Canadian ranking of possible causes of Atlantic salmon decline related to water quality issues.

Source: Cairns (2001).

Cause	Rank
High summer temperatures (from impoundments, riparian vegetation removal, decreased groundwater inflows, global warming) reduce juvenile production.	13
UV exposure (from stratospheric ozone reduction) in fresh water or in estuaries reduces survival of smolts.	14
Low pH of rivers (from acid rain) decreases survival of descending smolts.	19
Sedimentation processes (from soil erosion due to land use activities) reduce juvenile survival.	23
Disease transmitted from captive or escaped aquaculture fish.	24
Alterations in spring temperature regimes (from global climate change, impoundments, land use changes) increase smolt mortality.	26
Discharges of steroidogenic compounds (from pesticides or municipal sewage) comprise the parr-smolt transformation.	27
Naturally-occurring disease.	28
Sedimentation processes (from soil erosion) reduce egg survival.	35
Alteration of discharge patterns (from dams, water withdrawal, land use practices) reduce egg survival.	41
Toxic chemicals (e.g., agricultural and forestry pesticides, industrial discharges, mining wastes) affect smolt migration and reduce survival.	42
Limited availability of thermal refugia reduces juvenile survival.	44
Low pH due to acid precipitation reduces juvenile survival.	45
Toxic chemicals (e.g., agricultural and forestry pesticides, industrial discharges, mining wastes) reduce juvenile survival.	46
Low pH due to acid precipitation reduces egg survival.	47
Alterations in discharge regimes reduce the ability of smolts to reach the estuary.	49
Disease and parasitism reduce egg survival.	50
Alteration of discharge patterns reduce juvenile survival.	51
Pollution (e.g., pulp and paper mills, oil refineries, wood treatment plants, municipal sewage) in estuaries reduces survival of returning adults or lowers their ability to enter the river.	53
Alterations to discharge patterns reduce access to spawning areas.	54
Disease and parasitism reduce juvenile survival.	55
High water temperatures delay access to spawning grounds.	58

Addendum on Pesticide Usage in Maine Atlantic Salmon River Watersheds  
Mark Whiting

Pesticides and Blueberry Production

Blueberry production is the primary agricultural land use in the Downeast salmon river watersheds. Approximately 60,000 acres of blueberry land is currently in production (only half of which is actually harvested any given year). Approximately 60-70% of this acreage is located in Washington County (Yarborough, personal communication). Due to the favorable soils and coastal climate, almost all of the largest blueberry fields are located in Washington County. The potential problems for salmon restoration that might result from blueberry culture includes runoff of agricultural chemicals, including pesticides and fertilizers, soil acidification, and sediment entrained in stormwater runoff (both turbidity and total suspended solids, or TSS).

Originally blueberries grew wild in large fields of poor soil (generally shallow or sandy soils). The growth of larger woody plants was controlled by fire. This practice appears to date back before European contact. In the first half of the 20<sup>th</sup> Century blueberry culture was probably more extensive (perhaps as much as 200,000 acres) but was also fairly minimal in terms of cultural inputs (dominated by field burning on alternate years). In the 1930's calcium arsenate was the first pesticide used for blueberry maggot (Yarborough, personal communication). This was soon replaced by the development of organochlorine, and later organophosphate insecticides. In the latter part of the century, blueberry production has become more reliant on cultural practices to increase the volume and quality of the crop. This has resulted in a reduction in the number of acres but in more intensive management of the land (Bell, personal communication). Irrigation, fertilizer use, and pesticides rank as important cultural inputs. Table 1 provides a list of the dominant pesticides used on blueberries in Maine (adapted from Arter, draft of Narraguagus Watershed Management Plan). Of the fifteen chemicals listed, only six are applied regularly most years. The most commonly used are Orbit, Bravo, Benlate, Phosmet, Velpar, and Biobit.

In the 1940's the blueberry industry supported a tax on marketed berries to support research and development. Most of this research and development has been done by the Cooperative Extension office at the University of Maine. Cooperative Extension was the first to identify Velpar as a groundwater contaminant. In order to reduce pesticide use, the blueberry growers and the Cooperative Extension office have developed and promoted Integrated Pest Management (IPM, and the related idea of Integrated Crop Management or ICM). In the past 10 years, IPM/ICM have had a major impact on pesticide use in Maine (Wescott, Yarborough, personal communication). In this period, judicious use of pesticides has resulted in approximately a 70% reduction in their use. Cooperative extension provides annual training to growers. The larger growers often provide management expertise to the smaller growers. The result is that IPM practices have become widely adopted by the industry.

Table 1. Pesticide name, purpose, time of application, and type of application for the Maine low bush blueberry industry.

<b>PESTICIDE NAME Brand Name (Chem/Sci Name)</b>	<b>TYPE OF PESTICIDE</b>	<b>TIME OF APPLICATION</b>	<b>TYPE OF APPLICATION</b>
Orbit (Propiconazole)	Fungicide	Late April or May-Jun	Liquid: air/ground
Bravo (Chlorothalonil)	Fungicide	Spring	Liquid: air/ground
Benlate	Fungicide	May-Jun	Liquid: air/ground
Imidan (Phosmet)	Insecticide	April-Jun	Liquid: air/ground
Biobit ( <i>Bacillus thuringiensis</i> )	Insecticide	May-Mid June	Liquid: air/ground
Mycotrol ( <i>Beauveria bassiana</i> strain GHA)	Insecticide	Spring/Summer	Liquid: air/ground
Sevin (Carbaryl)	Insecticide	Spring/Summer	Liquid: air/ground
Velpar (Hexazinone)	Herbicide	March-Jun	Liquid: ground
Karmex (Diuron)	Herbicide	March-Jun	Liquid: ground
Sinbar (Terbacil)	Herbicide	March-Jun	<u>Liquid: ground</u>
Pronone (Hexazinone)	Herbicide	March-Jun	<u>Granular: ground</u>
Roundup (Glyphosate)	Herbicide	Spring	Spot application
Poast (Sethoxydim)	Herbicide	Spring	Spot application
Select (Clethodim)	Herbicide	Spring	Spot application
Fusilade (Fluazifop-p butyl)	Herbicide	Spring	Spot application

In terms of toxicity to animal life, insecticides are generally more toxic than fungicides, and herbicides are generally the least toxic of all. Fortunately, the greatest volume of pesticides used in blueberry culture are the herbicides, followed by fungicides, and the insecticides are the least (Wescott, Olday, personal communication). Table 2 shows LC 50 data for the most common pesticides used on blueberry fields (data from Exttoxnet <http://pmep.cce.cornell.edu/profiles/exttoxnet.html>).

In contrast to most other agricultural crops, blueberries are a relatively “low input” crop (Yarborough, personal communication). For instance, for high bush blueberries grown in New Jersey the bushes might be sprayed with Malathion on a twice per week rotation for about a month. In Maine, low bush blueberries might receive up to 2 insecticide sprays a year and only on a bearing year. Furthermore, in Maine malathion is no longer used on blueberries (Guthion or Sevin are used instead). For potatoes grown in Maine, Benlate might be sprayed on a 7-10 day rotation for most of the growing season. For low bush blueberries, Benlate is being discontinued. Orbit or Bravo are

Table 2. Acute toxicity data (LC 50) for selected pesticides to salmonid fishes.

PESTICIDE NAME	USE	SOIL MOBILITY	LC 50 for SALMONIDS
Orbit (Propiconazole)	Fungicide	Low	1,540 ppb for Rainbow Trout
Bravo (Chlorothalonil)	Fungicide	Moderate in sands	250 ppb for Rainbow Trout
Imidan (Phosmet)	Insecticide	Low	230 ppb for Rainbow Trout
Sevin (Carbaryl)	Insecticide	Low	1,300 ppb for Rainbow Trout
Sinbar (Terbacil)	Herbicide	High in sandy soils	46,200 ppb for Rainbow Trout
Velpar (Hexazinone)	Herbicide	High	320,000 ppb for Rainbow Trout

presently being used instead for blossom and twig blight, mildew, and leaf spot. Depending the weather (with cool wet springs being the worst) blueberries might be sprayed once or twice per year for these pests.

The Maine Atlantic Salmon Commission sampled the Narraguagus, Pleasant, and Machias River drainages for pesticide residues from 1991 to 1994. Screening was done on all the pesticides used in blueberry fields. Only Hexazinone (Velpar) was routinely identified and was found throughout the year (Magee 2001) in the Narraguagus and Pleasant Rivers. No other pesticides in the blueberry suite were found. DDT and DDE were found in some samples in the Narraguagus ranging from 12-314 ppb and 12-39 ppb respectively (Magee 2001).

The Maine Board of Pesticides Control (BPC) has done most of the recent environmental monitoring for pesticides used on blueberry fields. In 1987 the BPC conducted a spray drift study with Guthion. During aerial sprays, approximately 3% of the spray was estimated to have been deposited off-target (Jennings 1987). Most of the residues were close to the spray area and the concentration decreased with distance from the blueberry fields. Very small amounts of drift were found as far as 400 feet from the spray site (the farthest point where monitoring cards were located).

In 1997, the BPC began a survey of seven of the then official salmon rivers (Cove Brook has since been added to the list). Of 33 different pesticides or pesticide residues tested only Hexazinone (Velpar) was detected in the rivers. Hexazinone was found in 19 of the 64 samples taken, and was only found in the Narraguagus, Pleasant, and Machias Rivers. The concentrations ranged from 0.1-1.7 ppb (Chizmas 1999).

The Narraguagus and Pleasant Rivers were resampled in 1999. Six of eleven samples from the Narraguagus (54%) were positive for Hexazinone and six of nine samples from the Pleasant (67%) were positive. Again, of 33 chemicals screened for only Hexazinone was detected (Chizmas 2000). Because Hexazinone is applied in the spring but is found in the rivers throughout the year, and because Hexazinone is found in many wells in the Downeast area, and because it is known to be water soluble, the BPC

report concluded that the pathway for Hexazinone into the salmon rivers is likely to be groundwater discharge.

A study of drift during aerial pesticide applications was also conducted during the 1999 field season. Hexazinone was found in 11 of 13 samples taken from the Narraguagus and Pleasant Rivers. The highest Hexazinone detection (3.8 ppb) also had some Terbicil (0.148 ppb). In the 2000 field season, BPC concentrated on the detection of pesticide drift. Both Hexazinone and Phosmet were found in off-target areas on filter paper. Water samples were also analyzed. Hexazinone was found in most water samples taken near blueberry barrens. The insecticide Phosmet (Imidan) was found in three agricultural ponds that are tributaries to the Narraguagus and Pleasant River. The ponds are located immediately adjacent to blueberry fields and are used seasonally as sources of irrigation water. The ponds overflow in the spring but not in the summer. The concentrations of Phosmet in the ponds ranged from 0.08-0.52 ppb (Chizmas 2001).

In the 2001 field season, with the cooperation of the blueberry growers the BPC did more intensive studies of pesticide drift. A “worst case” study area was chosen on Bog Brook and Colonel Brook, perennial tributaries to the Pleasant River. Neither tributary has salmon habitat, but they enter the Pleasant at Crebo Crossing which has high quality salmon rearing habitat. An automated sampler (ISCO sampler) was used for the first time to get a more complete time series during spray events. The results of this study are still not available, but for the first time low concentrations of Phosmet and Chlorthalonil (less than 1.0 ppb) were found in the main stem of the Pleasant in salmon habitat (Chizmas, personal communication). Spikes of Phosmet ranging from 0.155 to 3.76 ppb were observed in Bog Brook. Because the spikes are intermittent (i.e., with detects alternating with non-detects), the drift appears to have been patchy. The sample interval was 15 minutes. There were no Phosmet detections in Bog Stream 3.5 hours after the spray application.

A comparison of the levels of pesticides found in the salmon rivers with the LD 50 values noted above shows that the pesticide concentrations are well below levels where acute toxicity is expected. The effects of chronic exposures to low concentrations of pesticides is largely unknown. New data on endocrine disruption suggests that for rare and endangered species a zero concentration of toxic materials is desirable. Maine Cooperative Extension is in the process of developing best management practices (BMP's) for reducing pesticide drift during ground and aerial applications (see Fact Sheet No. 303 now in draft form). Most of the BMP's involve the fine tuning of the spray equipment, timing and weather, etc. However, planted or natural buffers, especially evergreen ones, are now highly recommended whenever there are sensitive nearby surface waters. These BMP's will be integrated into existing IPM/ICM programs.

Fertilizers are another major input in blueberry cultivation. Either mono- or di-ammonium phosphate are applied in the late spring. The application may be as a liquid or in a pelletized form. Due to the sandy soils where blueberries are commonly grown, some nutrient enrichment of soil leachates are likely. Also due to the sandy soils, stormwater runoff from blueberry fields is unlikely except on frozen or saturated ground. Thus groundwater is the most likely path for excess nitrates. Phosphate is typically bound in soils and is not very mobile unless the soil particles themselves are transported (such as road runoff and eroding slopes).

In the Downeast rivers, nitrates during baseflow conditions tend to be very low (generally < 1.0 to 2 µeq/l, see Whiting, 2001). However, some sample sites have considerably higher concentrations. Bog Stream flows out of blueberry barrens and into the Pleasant River at Crebo Crossing. Nitrate concentrations here range from 4.6 to 13.1 ueq/l in Bog Stream and 2.1 to 3.4 µeq/l at Crebo Crossing. Relatively high nitrate concentrations found on the lower Pleasant River in Columbia Falls (1.0-7.0 ueq/l) appears to be due to septic problems not agricultural inputs (high *E coli* counts also occur in this region).

Lake water chemistry is available from a number of lakes in the Narraguagus River watershed. Phosphorus is generally the limiting nutrient in lakes. Table 3 provides values of total P in these lakes and two sites in the river (adapted from Arter, draft of Narraguagus Watershed Management Plan).

Table 3. Total phosphorus concentration in selected water bodies.

WATER BODY	P MAX (ppb)	P MIN (ppb)	AVERAGE (ppb)	SENSITIVITY TO INCR. P
Beddington Lake	18	1	10	LOW
Schoodic Lake	51	1	11	HIGH
Spruce Mtn. Lake	26	1	8	
Cable Pool (river)	24	11	15	
West Branch (river)	21	15	18	

The average concentration of total P in Maine lakes is 14 ppb (PEARL website). Rivers with 10-20 ppb of phosphorus may experience seasonal blooms of periphyton if the sites are warm and sunny. Periphyton blooms have been noticed at the Cable Pool on the Narraguagus, at Whitneyville on the Machias, and below the fish hatchery on Chase Mill Stream on the East Machias River (Whiting, personal observation). This appears to be a site specific problem rather than a river-wide problem.

Turbidity and Total Suspended Solids (TSS) are site-specific problems found in all of the Maine salmon rivers. In the Downeast rivers the problem is generally related to specific road crossings or land management roads. However, agricultural fields can also be a source of suspended sediment. An example was found on Tunk Stream in the town of Steuben. A blueberry field drained down a steep slope into a gravel pit and then directly into Tunk Stream. Cherryfield Foods Inc. one of the large growers in the area helped the owner fix the problem once it was brought to their attention. The gravel pit was excavated to serve as a settling pond and gully erosion in the farm roads were filled with local stone. In surveys of the non-point source pollution sources in the watersheds of the Narraguagus and Pleasant Rivers, almost all of the sources have been land management roads and road crossings rather than direct erosion from fields (Project SHARE NPS database).

### Pesticides and Forestry Management

Forestry is the dominant land use in most of the Downeast salmon rivers. The Pleasant River is the exception, where blueberry lands are dominant. International Paper

(IP) alone has approximately 340,000 acres of forest lands in the salmon river watersheds (Donovan, personal communication). The riparian strips (or the Shoreland Zone) and some other special habitats (Resource Protection areas) are the least intensively managed of the forest lands. The width of the riparian zones varies from 75 feet on either side for the smaller streams (called PSL2 streams in LURC territory, streams that drain from 300 acres to 50 square miles), to 250 feet (for PSL1 streams and rivers that drain over 50 square miles). IP has its own riparian management zones that are more restrictive than state standards. IP uses a stream protection area of 330 feet on either side of a third order stream, and 660 feet for fourth order streams and larger. While some cutting and other management is allowed in the riparian zones, IP uses no sprays. State law does not presently prohibit the use of herbicides in riparian zones within the salmon river watersheds.

Outside of the riparian zones, IP does use herbicides. In order to encourage the regrowth of softwoods, Garlon (Tricyclopyr) and Accord (Glyphosate) may be sprayed. Generally, sprays are used on one site for no more than a year or two, no more than one spray a year. Since the harvest frequency is about 35-40 years for pulpwood and 80 years for saw logs, the spray frequency is no more than twice in that period. Furthermore, selective harvests generally do not usually require sprays to accomplish the regrowth objectives. Sprays are generally only used on clearcuts or other special applications (Donovan, personal communication). Other landowners have similar management practices that include some herbicide use. In terms of acreage or the amount of spray used, forestry is not as intensive as agriculture or home lawn care.

Insecticides were used during the spruce budworm outbreaks in the late 1970's through the mid 1980's. Sevin, Dylox, and Orthene were primarily used early on, but a *B.t.* spray was being used in the salmon river watersheds by the end of the outbreak (Donovan, personal communication). Maine Bureau of Forestry reports from this period show that Sevin had a potential for large impacts on stream invertebrate communities, but generally did not have a noticeable effect on fish (Maine Dept of Conservation, series of reports). Insecticides have not been used since the spruce budworm outbreak for forestry management, not even for hemlock looper outbreaks in the 1990's and in 2001.

### Pesticides and Road Maintenance

The maintenance of road rights-of-way can be broken down by costs as approximately 50% for mowing, 10% for brush cutting, and 40% herbicide spraying for brush control (Moosmann, personal communication). Herbicides were first used in the mid-1960's on roadsides in Maine. However, in the past few years, sprays are not used at all in Division 2 (Washington and Hancock Counties) due to concerns about the health of the salmon rivers.

Outside of Division 2, a 50/50 mix of Tricyclopyr (Garlon) and Tricamba (Vanquish) are used for most roadside spray applications. Buffers of 100 feet are maintained along the Sheepscot and Ducktrap Rivers and Cove Brook, and no sprays are used within 50 feet of other surface waters. No sprays are applied during spring; and no sprays are applied on puddled water or bedrock. The maintenance crews are contractors that MDOT uses each year. The contractors receive training in MDOT's spray protocols even if all the employees have previous experience.

Glyphosate (Roundup) is rarely used for roadside maintenance and is only reserved for special applications. For instance, it might be used to clear areas of vegetation for special landscaping projects or the sowing of wildflowers. In the last 5-10 years there has been a large reduction in the reliance on pesticides and in the application rates. Today, Garlon and Vanquish are applied at a rate of 0.23 quarts of product per linear mile (and only if it has brush). Due to the relatively low toxicity of herbicides and the low application rate, roadside maintenance is not thought to represent a threat to the health of salmon.