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Agribusiness and Atlantic Salmon:

The effects of large-scale blueberry production on endangered Atlantic salmon

Maine Environmental Policy Institute

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The mission of MEPI is to help Mainers understand the importance of healthy ecosystems to their families and communities. The Institute, an independent nonprofit organization based in Hallowell, Maine, is dedicated to researching environmental challenges facing the state and reporting this research to policy makers and the public.

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Introduction

Historically, Atlantic salmon (*Salmo salar*) populations ranged throughout the New England states, south to Long Island Sound, and Atlantic Canada. In the United States, salmon runs were divided into three Distinct Population Segments (DPSs), or populations that would interbreed when mature (USFWS/ NMFS, 2000). These DPS regions were delineated to include the Long Island Sound, Central New England, and Gulf of Maine Distinct Population Segments. The first two populations have been extirpated and no longer exist. The final existing population, the Gulf of Maine DPS, originally extended down to the Androscoggin River. The Androscoggin no longer supports Atlantic salmon runs, but the remaining rivers in the Gulf of Maine DPS still have "functioning wild salmon populations, although at substantially reduced abundance levels" (USFWS/NMFS, 2000).

Located in the Downeast region of Maine, these rivers include the Dennys, East Machias, Machias, Pleasant, Narraguagus, Ducktrap and Sheepscot Rivers, and Cove Brook. Acknowledging the declining Atlantic salmon populations, the National Marine Fisheries Service and the U.S. Fish and Wildlife Service decided to classify the Atlantic salmon in this DPS as endangered, with the full protection under the Endangered Species Act (ESA). At the time of the listing, members of industry and some in the scientific community expressed concern about the classification of Atlantic salmon as endangered due to the effects of stocking and aquaculture on the population's genetic distinctness (USFWS/NMFS, 2000). Additionally, many other stakeholders expressed apprehension regarding the listing because of the potential affect on agriculture and other land use in the Atlantic salmon's habitat. Thus the stage was set for a formal state-wide review of the relative importance of wildlife preservation versus human agriculture interests.

The Endangered Species Act (ESA), aside from making it illegal to harm or kill endangered species (both directly and indirectly), also mandates federal, state, and local agencies to ensure that their actions do not harm these species, or negatively impact their recovery (USFWS, 2001). With the listing of Atlantic salmon, regulation of pesticides, pesticide use, water withdrawal and water pollution by federal, state and local agencies was required to conform to ESA standards. Two of Downeast Maine's prominent industries, agriculture and forestry, threaten various aspects of Atlantic salmon survival and have been under greater scrutiny following the listing. A recent report released by the Maine Environmental Policy Institute detailed the impacts of the forestry industry on Atlantic salmon (Lansky, 2004). This report will explore the effects of blueberry cultivation on Atlantic salmon in the endangered DPS.

Agencies cite a number of issues that should be addressed for Atlantic salmon recovery. For example, the National Academy of Sciences (2004) listed dams as the largest threat to Atlantic salmon, but stressed the importance of monitoring water quality and stream flow. Project SHARE (Salmon Habitat and River Enhancement) emphasizes the importance of monitoring non-point source pollution (NRWC, 2003). Additionally, the recovery plan for Atlantic salmon drafted by the USFWS and NMFS (2004) listed water withdrawals and acidified water as two critical threats to their survival. Common agricultural practices of blueberry cultivation can affect all of these factors in Atlantic salmon recovery. This report will address the potential threats to the Atlantic salmon caused by the blueberry industry, specifically sedimentation, nutrient loading, pesticide contamination, water withdrawal, wastewater discharge, and acidification.

The report's findings include:

- Sedimentation from low-maintenance roads throughout fields near Downeast rivers create increased problems with sedimentation of gravel beds, which are important Atlantic salmon egg and alevin habitat;

- Nutrient loading is not extensive, but there is some potential for fertilizer application to fields to cause algal blooms and decreased dissolved oxygen in nearby streams and rivers;

- Pesticides used on blueberry fields have limited acute toxicity to Atlantic salmon, but indirect and chronic effects may be severe;

- Hexazinone- this oft-used herbicide is likely in concentrations from drift, runoff and groundwater seep high enough to change aquatic organismal communities, decreasing fitness of fry and parr;

- Malathion and azinphos-methyl may have direct, acute effects on Atlantic salmon physiology and survival, even in low concentrations;

- Water withdrawal can dramatically affect Atlantic salmon and the entire aquatic ecosystem, particularly in the late summer and early fall;

- Discharges from processing plants and other wastewater may have adverse effects on water temperature and dissolved oxygen in rivers, but is limited to small portions of Atlantic salmon habitat;

- Sulfur applications to increase acidic soil conditions are infrequent and sporadic, yet may be of concern for all life stages of Atlantic salmon.

Introduction to Salmon Biology

The following section serves as a brief introduction to the biology of Atlantic salmon; see also Netboy (1974) and Mills (1989) for further detailed information on salmon biology.

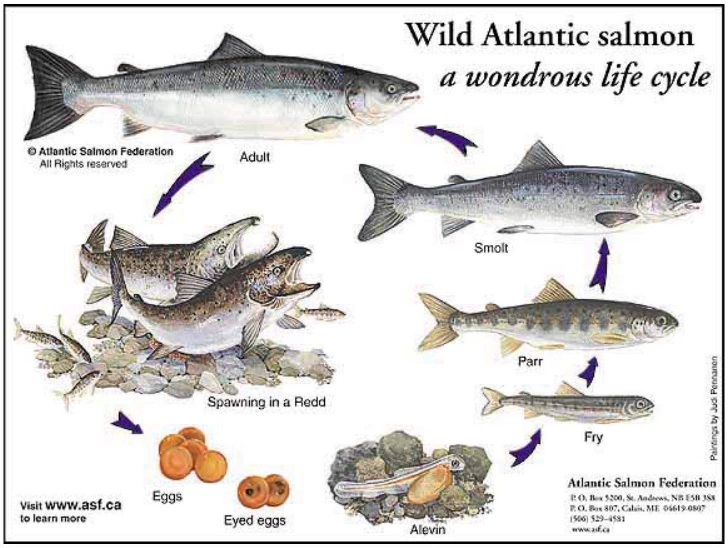
Atlantic salmon are anadromous fish, meaning that they spend part of their lives in freshwater and the other part in seawater. Atlantic salmon bury their eggs among gravel in cool, freshwater streams, and hatch in late winter and early spring after an incubation of approximately 110 days (Netboy, 1974). The hatchlings, known as alevins until they absorb the yolk sac, remain in the gravel substrate until they emerge as fry. The fry feed in these streams; after they reach approximately 2” in length, they are known as fingerlings, or parr. The parr are territorial and spend approximately 2 years feeding on various prey organisms in the upstream aquatic ecosystems (Mills, 1989).

The parr-smolt transformation is considered the most stressful of an Atlantic salmon’s life. Many physiological changes occur during this period, the body form and color changes; the fish also undergo biochemical modification in order to survive the transition to salt water when they migrate downstream. This parr-smolt transformation takes approximately one month; after its completion, the smolts go to sea, where they feed and grow larger, preparing themselves for reproduction. Their downstream migration is affected by water quality, particularly its temperature and dissolved oxygen content.

The adult salmon return to their home streams. Exactly how they do this is still unknown. Adult salmon do not feed once they return to fresh water. The adult salmon need conditions similar to those of smolts: good stream water quality, especially dissolved oxygen content and cooler temperatures and upstream passage. In Maine, this migration occurs in the spring and the adults spawn in the fall, restarting the life cycle. Two individuals of the opposite sex can theoretically keep a salmon run alive. However, a larger population is needed to ensure genetic variability and a sustainable salmon run.

With the exception of the adult, all stages of the salmon’s life cycle are dependent on water quality and quantity in the shallow streams in which they reproduce. Without good water quality, adults cannot complete their upstream migration to reproduce. Therein, without adequate water movement, the buried salmon eggs will suffocate. Furthermore, without available prey, the juvenile salmon will starve. When Atlantic salmon are exposed to pollution, they can suffer developmental abnormalities and stress. When faced with poor water quality downstream, smolts cannot complete their migration to the ocean’s rich food sources.

Figure 1. Diagram of Atlantic salmon life cycle.



Sedimentation

Adult female salmon deposit their eggs in redds, or depressions dug 15-30 cm deep into gravel substrate in upwater streams (Mills, 1989). Eggs remain in these redds over winter, after they hatch. The gravel substrate allows water movement, which prevents the eggs from suffocating. The addition of smaller size particles can decrease water flow, leading to egg suffocation. In general, the substrate should be 80% gravel, with no more than 20% sand, silt, or smaller particles, for good egg survival (Mills, 1989). Sedimentation may also affect the general health of aquatic ecosystems, thereby influencing water flow in shallower, more ephemeral streams.

Particles can enter upwater stream portions through runoff from the land. Since lowbush blueberries are perennial crops, they are not associated with soil disturbance as with annual crops, where tillage may occur multiple times in one season. However, there is a preponderance of low-maintenance roads in blueberry barrens. For example, the Narraguagus River Watershed Council, for example, estimates that in the 6000 acres of the river's watershed that are cultivated for blueberries, there are over 200 miles of low-maintenance dirt roads in blueberry barrens (NRWC 2003). These roads, combined with other unpaved roads including poorly maintained town roads and those used for logging, constitute the largest non-point source pollution threat to the Narraguagus River (NRWC 2003).

Unpaved roads may contribute to the sedimentation of salmon spawning grounds through runoff from impervious surfaces, as well as from unstable shoulders, faulty culverts, and inadequate ditching. There has been little direct tracking of sedimentation to roads used by the blueberry industry, so the extent of this threat is difficult to determine.

Nutrient pollution

Aquatic zones near crop production areas are often affected by eutrophication, or nutrient overloading. Excess levels of nitrogen and phosphorus compounds can lead to blooms of phytoplankton, unicellular plants that form the lowest trophic level and foundation of aquatic food chains. Often, these blooms become so thick that they shade out vascular aquatic plants. When the blooms crash and the organisms die, they are decomposed by bacteria using oxygen, creating zones of little or no dissolved oxygen. These anoxic zones are extremely detrimental to fish, which require oxygen to breathe. Nutrient loading is most pronounced in the lower portions of rivers where nitrogen and phosphorus are found in greater concentrations. In particular, anoxic zones in estuarine areas may affect upstream salmon migration, since they must avoid these areas in order to survive. Extra swimming to avoid these zones may add further stress to migrating salmon and use up precious energy reserves. This issue will be discussed in further detail in the section about blueberry processing and wastewater discharges, because anoxic zones are more typically associated with nutrient pollution from blueberry processing, not cultivation.

With annual crops, fertilizers are applied at the time of planting and/or spread as the plants grow. Since wild blueberries are perennials (that is, they are not replanted every year), fertilizing can be much more difficult because excess nutrients may cause harm to the plant. In addition, the nutrient requirements of the blueberry plants cannot be determined by nutrient levels in the soil. Therefore, cooperative extension agents recommend foliar testing to adequately assess the nutrient needs of a particular field (Smagula and Yarborough, 2004). Heavy fertilization is recommended when establishing new blueberry plantings or attempting to fill bare spots in fields, particularly in areas with little to no organic matter layer (DeGomez and Smagula, 1990). Since blueberries are grown in low pH soils, the major form of nitrogen used by the plants is ammonia (NH_4). Thus, urea, an organic nitrogen compound, is the recommended form of nitrogen for application rather than nitrate (Yarborough and Smagula, 1993). Additions of urea to aquatic systems can also cause excessive phytoplankton growth, just as with nitrate. Despite the fact that wild blueberries form mycorrhizal associations, an adaptation for “mining” phosphorus from low-phosphorus soils, foliar phosphorus in blueberry cultivation is often too low and supplemental P must be applied (Yarborough and Smagula, 1993). Depending on the nitrogen needs of the plants, either mono- or diammonium phosphate is applied. Phosphorus, particularly in lower pH soils, is tightly bound to soil particles and with the advent of rain or snow melts, runoff will most likely occur. Efforts to avoid applying fertilizers before such events can help prevent runoff to aquatic systems, particularly when fertilizer is applied to bare areas, as they are more prone to erosion.

As with sedimentation, the threat of nutrient pollution to these aquatic systems remains relatively unknown. Though increased monitoring is in place in portions of certain rivers, the nutrient status of most rivers remains unclear. Continued foliar testing, along with planting buffers along streams, may contribute to decreasing fertilizer usage and help mitigate problems caused by fertilizer applications.

Pesticides

Pesticides, including herbicides, insecticides, and fungicides applied to lowbush blueberries represent a potentially large, yet relatively unknown threat to Atlantic salmon. These toxic compounds may affect salmon in a variety of ways. For example, they may be *acutely* toxic to salmon, in which one exposure to a large chemical dose will kill the fish. Conversely, salmon may suffer from *chronic* exposure or repeated exposure at lower concentrations that have adverse effects on the fish's health that may ultimately result in death. In addition, pesticides may have *indirect* effects on salmon health by harming the aquatic ecosystems that salmon depend on for survival. Typically, chronic and indirect effects do not kill fish outright but decrease their fitness and survival rates. Acute toxicity, chronic exposure and indirect effects from a number of oft-used blueberry pesticides will be discussed in this section.

Pesticide registration for use in the United States requires testing the toxicity of the pesticide on various organisms, but this does not mean that all appropriate testing is done or that standards are created for most pesticides. The Environmental Protection Agency (EPA) uses aquatic life criteria established by the National Academy of Sciences and the National Academy of Engineers to protect aquatic ecosystems from exposure to toxic levels of pesticides (Ewing, 1999). However, these standards exist for a minute number of pesticides. For example, in 1999, of the 55 insecticides most widely used in agriculture, criteria exist for only six (Ewing, 1999). None of the 96 herbicides or 30 fungicides most heavily used implemented standards. For those that had standards, the criteria used were developed in 1973 and are considered outdated because they only address acute toxicity and do not address sub-lethal chronic exposure or bioaccumulation. In addition, the EPA has no standards or tests to measure the effects of secondary compounds, carriers, surfactants, adjuvants, breakdown products or combinations of all of those, some of which are as powerful and toxic as the active ingredients.

The Environmental Protection Agency is bound by law (USFWS, 2001) to not allow the use of chemicals that are harmful to endangered species. To that effect, new regulations are currently being formulated to examine the impacts of pesticides, inert ingredients, and breakdown products on ecosystems containing endangered or threatened species, in an attempt to determine the actual ecological risk of a pesticide (EPA, 2004). Evaluation of these risks only occurs when a pesticide manufacturer is trying to register a pesticide, or when that pesticide is up for reregistration (EPA, 2004). The process is lengthy and involves many different agencies. Subsequently, while baseline standards may exist for protecting at-risk ecosystems, it by no means protects *all* ecosystems from potentially harmful pesticides.

Despite the short-comings of pesticide toxicity testing required, acute toxicity to fish is assessed generally as part of the pesticide registration process. The fish experience acute toxicity when they encounter pesticides at high levels. Most compounds applied to blueberry barrens occur at low levels, making it unlikely that Atlantic salmon would be killed by normal pesticide application. However, accidental spills or improper mixing could contribute to toxicity of these compounds.

Chronic exposure to pesticides is a different case. It is very difficult to perform assays of chronic toxicity and few detailed studies exist, particularly as it relates to Atlantic salmon. However, there is scientific evidence that chronic exposure to low doses of certain pesticides can interfere with a number of salmon behaviors and adversely affect health (Ewing, 1999; Lind, 2002). In addition to the pesticides themselves, secondary compounds found in pesticide formulations, including surfactants, mixers, and inert ingredients are suspected to create problems as well.

Two herbicides, hexazinone (Velpar ® and Pronone ®) and glyphosate (Roundup® and Touchdown®), comprise 85% of the total herbicide application in the blueberry industry, while three insecticides, azinphos-methyl (Guthion®), phosmet (Imidan®), and malathion (Malathion®), account for 83% of the total insecticide applications (Dill et al, 1998). Propiconazole (Orbit®) and fenbuconazole (Indar®) are the two commonly applied fungicides.

Table 1. Commonly used blueberry pesticides and their human health and environmental effects.

Pesticide	**Trade Name**	**Common Uses**	**Human Health Hazard**	**Environmental Hazard**
Malathion	Malathion®	Used on a variety of insects; In a variety of locations including forests, greenhouses, and blueberry barrens	Class III Pesticide: Caution; A neurotoxin: many neurological problems in large doses	Toxic to wide range of fish, amphibians, and birds
Glyphosate	Roundup®, Touchdown®	An Herbicide; Kills a variety of weeds; Is ubiquitious in commercial use and personal gardens	Not Directly Toxic; Some degenerative by-products cause tumors	Some inert ingredients toxic to marine animals
Hexazinone	Velpar®, Pronone®	An Herbicide; Kills broadleaf weeds, grasses and woody plants; Used in aerial spraying commercially	Can produce developmental defects in high doses	Not particularly toxic to marine animals, but can be harmful to endangered poplulations
Propiconazole	Orbit®, Banner®	A fungicide; Is ubiquitous in commercial use	Can generate tumors in high doeses chiefly in male victims	Slightly to moderately toxic in a wide spectrum of fish species

Hexazinone

Hexazinone, a widely used herbicide in blueberry cultivation, is applied at 0.4-0.5 kg of active ingredient per hectare (calculated from Yarborough, 2004). *Direct* application of this concentration to a stream 15 cm (approximately 6”) deep *could* theoretically result in a hexazinone concentration of 0.29 mg/L of water, a concentration known as the maximum expected environmental concentration (EEC). Such direct application could only result from an accidental overspray of a stream. Spills of concentrated pesticides and improper mixing, resulting in higher concentrations, may occur. Storm events immediately following an application can also result in higher hexazinone concentrations in streams. For example, a maximum hexazinone concentration of 0.44

mg/L was found in a stream during a storm that occurred three days after application to forest plots (Neary et al, 1983). A higher concentration of pesticide, 1.36 kg active ingredient per hectare, was applied in this example. Extrapolating downward to the 0.4-0.5 kg active ingredient per hectare applied to wild blueberries, the stream concentration would be 0.13-0.16 mg/L hexazinone during a similar storm event. Drift from pesticide spraying could result in lower concentrations than runoff in nearby streams, and the Maine Board of Pesticide Control (BPC) monitors have frequently detected hexazinone at times not immediately following hexazinone application (MBPC, 2003). Hexazinone is quickly lost from the soil after an application (Jensen and Kimball, 1987), suggesting that once it is applied, it is not likely to slowly leach from the soil into surface water. However, hexazinone has contaminated groundwater throughout the areas near blueberry fields. It is important that the potential consequences of herbicide application and drift be monitored, particularly considering that the microscopic phytoplankton that form the base of these aquatic food chains are extremely sensitive to herbicide exposure.

Hexazinone, marketed as Velpar® or Pronone®, is not *directly* and *acutely* toxic to fish except at very high concentrations (Wan et al, 1988). For juvenile Pacific salmonids, the LC_{50}, or the concentration at which 50% mortality in a test population occurs, for Pronone® 10G is well over 1 g/L, many orders of magnitude greater than the EEC. For Velpar®, this concentration is slightly lower, but still greater than 800 mg/L in most cases, again much higher than would be expected from accidental overspray or runoff. Carriers present in these two hexazinone formulations were toxic only in extremely high doses. Hexazinone, measured as an active ingredient, is more toxic, but still requires a concentration greater than 250 mg/L to kill juvenile Pacific salmonids.

The indirect effects of hexazinone on Atlantic salmon may be substantial. Hexazinone concentrations lower than the EEC reduce biomass and chlorophyll photosynthetic activity of different phytoplankton species, resulting in potential *indirect* effects on salmon health. Primary productivity of various algal species was inhibited by hexazinone concentrations of 22.5 µg/L (Williamson, 1988). The EC_{50} value, or the concentration above which 50% growth inhibition occurs, varies depending on the species. For *Selenastrum capricornutum* and *Anabaena flos-aquae*, the EC_{50} value is 30 µg/L, two orders of magnitude less than the max EEC (Abou-Waly et al, 1991). For different species of diatoms and green algae, this concentration ranges from 9 µg/L to 60 µg/L (Peterson et al, 1997). Duckweed, a vascular plant, had intermediate sensitivity, with an EC_{50} value of 72 µg hexazinone per liter. Exposing various algal species to the EEC of hexazinone for forestry applications, which applies hexazinone at 4-5 kg active ingredient/hectare, reduced carbon uptake by 50% and growth of duckweed by 50% (Peterson et al, 1994). Cyanobacteria, or blue-green algae, is less sensitive to hexazinone exposure, with EC_{50} values ranging from 143 µg/L to over 2,000 µg/L (Peterson et al, 1997). Different sensitivities to hexazinone could change plant community diversity during prolonged exposure to hexazinone, with ramifications for the entire food web. Green algae and diatoms are the preferred food source of many zooplankton species, while cyanobacteria, less sensitive to hexazinone, are relatively poor food sources (Peterson et al, 1997). Without appropriate food sources, zooplankton populations may decline, reducing food availability for developing Atlantic salmon.

Here in Maine, researchers from the University of Maine Orono have been trying to unravel the mystery of the disappearance of eelgrass in Taunton Bay (Osher, 2005). According to preliminary research, the eelgrass disappearance is likely due to nutrient enrichment or hexazinone contamination (Osher, 2005). Nutrient enrichment from processing wastewater and fertilizer runoff could be connected to blueberry cultivation, but will be considered in another section. In the Great Barrier Reef, the agricultural herbicide Atrazine, a triazine chemical, was identified as the culprit of eelgrass decline. Hexazinone, also in the triazine chemical family, from contaminated groundwater may have reached the estuary about the same time as the start of the eelgrass's decline (Osher, 2005).

In a study of an enclosed lake system in Canada, a "lentic" system, researchers determined that chronic exposure to hexazinone concentrations as low as 0.1 mg/L resulted in "persistent impacts" on the resident phytoplankton community (Thompson et al, 1993a). These impacts included reduction in biomass and changes in the phytoplankton community structure. At this lower concentration, dissolved oxygen concentrations remained fairly constant, but dropped when the systems were exposed to concentrations upward of 1.0 mg/L. Similarly, applying hexazinone to enclosed bog lakes, ranging from an equivalent application rate of 0.4 kg AI/ha (as recommended for blueberries) to 4.0 kg AI/ha (as recommended for most forestry applications) led to a dose-dependent response in dissolved oxygen content (Solomon et al, 1988). Hexazinone at 1 ppm, or 1 mg/L in test ponds led to a decline in dissolved oxygen from 8 ppm to 0.2 ppm after five days, coinciding with a fish kill four days post treatment (Anderson, 1981); periphyton and invertebrate biomass was also decreased by this treatment. Certain types of phytoplankton, including cryptophytes, seemed to be more tolerant of hexazinone exposure, indicating that community shifts could result from repeated exposure to this herbicide. These changes in the primary producers in aquatic ecosystems can result in dramatic fluxes up the food chain. For example, consistent reductions in the phytoplankton biomass resulting from exposure to 1.0 mg/L of hexazinone resulted in a corresponding decrease in zooplankton abundance, these creatures were the next tier in the food chain above the primary producers (Thompson et al, 1993b). Populations of these primary consumers did rebound, but 3-4 weeks after the last exposure to hexazinone. Typically, zooplankton and higher orders on the food chain, including fish, are less sensitive to herbicide exposure; however scientists found hexazinone was toxic to various test insects at a concentration of 80 mg/L, much higher than expected (Kreutzweiser et al, 1992). Even though these systems can rebound after a large decrease in phytoplankton abundance, this process takes time. An accidental overspray or spill of herbicides could result in an aquatic system with greatly decreased health for weeks to months, depending on the severity of the contamination. Hexazinone, while it is very water-soluble, may persist in northern lake environments for months (Thompson et al, 1992) to years (Williamson 1988). This contamination affects the food supply for young salmon and could cause mortality. Moreover, the reduced oxygen supply could affect salmon development, maturation, and even the success of a migratory run, as all these stages are dependant on waterways with healthy adequate content. Although Atlantic salmon spend little or no time in lakes, blueberry pesticide applications could have profound affects on these biological systems.

Most Downeast salmon habitat streams are flowing, or “lotic” systems. Flowing water may help reduce the negative impacts of accidental oversprays or spills because pesticide may become diluted and flushed out of the system more quickly than in a lake. This is especially probable because hexazinone does not adhere to sediments and is highly soluble in water. However, these systems can still suffer adverse effects when exposed to chronic pesticide loading. A study designed to assess these impacts pulsed hexazinone into streams over a 24-hour period, attempting to mimic the loading that would be associated with a rainfall event following spraying (Schneider et al, 1995). The average concentration of hexazinone in these streams ranged from 0.15 mg/L to 0.43 mg/L, similar to that which could be expected from an accidental overspray. The productivity of periphyton, phytoplankton attached to the rocks and stream bottom, significantly decreased in streams with hexazinone compared to streams with no pesticides added. Biomass was not affected and productivity of these communities was quick to recover after pesticide loading ceased. Abundance of macroinvertebrates (mostly insects) captured in drift nets in the study streams did not differ between treated and untreated streams. In this study, the EC_{50} value for the periphyton community was determined to be only 3.6 µg/L, less than was initially determined for single species in the laboratory.

Malathion and Azinphos-methyl

A number of studies have addressed the impact of hexazinone on different aquatic systems. This focused research is most likely due to the forestry industry’s heavy use of hexazinone. Less is known about the other various insecticides and fungicides used in blueberry cultivation. Out of the five other insecticides and fungicides commonly used in blueberry cultivation, only malathion and azinphos-methyl were reviewed in scientific journal articles. Malathion, an organophosphate insecticide, is toxic to many organisms in aquatic ecosystems, including amphipods (Crane et al, 1995), insect larvae (Overmyer et al, 2003), and fish (Prentiss Incorporated, 2001). Several variations of malathion are used for insect control so concentrations in the environment can vary (Yarborough 2004b).

Unlike hexazinone, malathion may more directly harm fish species. For example, exposure to malathion reduced the preferred temperature of juvenile salmon (Peterson, 1976) and may cause developmental malformations in the Atlantic silverside (*Menidia menidia*) at concentrations as low as 10 ppb, or 10 µg/L (Weis and Weis, 1976). Sublethal doses of malathion led to four times lower diffusing capability of the gills of freshwater carp (*Cirrhinus mrigala*), with short term exposure causing gill inflammation and long term exposure causing gill epithelium loss (Roy and Munshi, 1991). Researchers noted behavioral changes in bluefish exposed to malathion. Bluefish responded to visual stimuli with hyperactive behavior after exposure to 16 µg/L of malathion and extreme lethargy at exposure to 48 µg/L of malathion (Richmonds and Dutta, 1992).

Studies of azinphos-methyl’s affect on aquatic life illustrate how numerous species may react differently to various pesticides. For low doses of azinphos-methyl of 2 µg/L, scientists found no change in acetylcholinesterase activity, a measure of immune system function, in a number of invertebrate species (Day and Scott, 1990). However, carp in lakes with very low, yet still detectable, azinphos-methyl concentrations did have decreased cholinesterase activity (Gruber and Munn 1998). For damselfly larvae, the LC 50 of azinphos-methyl ranged from 26.6 to 50.2 µg/L, with damselfly eggs being much more resilient to this insecticide (Hardersen and Wratten 2000). Tracking azinphos-methyl in streams following aerial spraying, Schulz (2001) found that with normal application rates in fruit orchards, and with normal stream discharge of 0.28 m^3/sec, the azinphos-methyl concentration was 0.04 µg/L. During storm events, with higher stream discharge ranging from 7.5-22.4 ft^3/s but also higher inputs from runoff, these concentrations increased to 0.26-1.5 µg/L. Clearly, existing insecticide and fungicide practices have the potential for dramatically increased impact upon streams and wildlife following storm events.

Dangerous Chemical Interactions

In addition to the effects produced by the pesticides themselves, it is important to note that exposing organisms and ecosystems to combinations of pesticides may perhaps be even more damaging. In these "environmentally realistic mixtures," pesticides may act synergistically (Overmyer et al, 2003; Connors and Black 2004). In addition, the impacts of carriers, inert ingredients, and pesticide breakdown products on salmon and aquatic ecosystems are rarely studied. However, in one study, it was demonstrated that 4-nonyl phenol, a compound commonly used in forestry pesticide formulations, interferes with the parr-smolt transformation of Atlantic salmon. It has been suggested that this compound is partially responsible for declines in Canadian populations of Atlantic salmon (Madsen et al, 1997; Arsenault et al, 2004).

Barring application accidents, spills, severe drift or storms immediately following application, it is unlikely that pesticide loading into Downeast salmon rivers from normal blueberry cultivation practices would result in high enough concentrations to *directly* impact the Atlantic salmon. Current research on the direct effects of hexazinone and phosmet on salmon fry survival and the parr-smolt transformation is being conducted at the University of Maine (Ben Spaulding, personal communication). However, the potential *indirect* effects are enough to engender immediate concern. The Maine Board of Pesticide Control has detected two of these compounds (phosmet and propiconazole) in drift studies, albeit at very low concentrations (MBPC, 2003). However, the authors of this study note the difficulties they faced in trying to measure pesticide drift from aerial applications, including communicating with aerial applicators to time the placement of monitoring equipment. These surveys, while rigorously conducted, were far from complete and adequate to assess the drift of pesticides into surface waters. The recent news that Cherryfield Foods and Jasper Wyman and Son, both of which were caught contaminating local rivers with aerially sprayed pesticides, will be ceasing aerial applications of pesticides will help mitigate pesticide contamination of these surface waters (Ellis, 2004). Monitoring is still necessary to ensure that the waters are and will maintain low pesticide levels. See appendix A for maps of Cherryfield Foods and Jasper Wyman and sons and their proximity to local river systems.

Groundwater monitoring for hexazinone may serve as a model of how different agencies can work together to address public concern and the threats posed by pesticides. Due to its water solubility and low potential to adhere to soil particles, groundwater contamination by hexazinone is relatively high. Public concern about high levels of the pesticide in the Narraguagus High School and other drinking water supplies has led to the development of extensive ground and well water monitoring throughout Downeast Maine by various agencies. Along with improved detection capabilities (Perkins, 2002), this monitoring has proved that, with a few minor exceptions, hexazinone concentrations in test wells have declined as integrated pest management strategies have been implemented by blueberry growers (Yarborough, personal communication and unpublished data.) Similar monitoring programs for other pesticides, nutrient levels, and sedimentation should be implemented.

Table 2. Pesticides Found in Narrauagus River Watershed Summer 2004 (BPC data).

Site	**Amt. Imidan® (ppb)**	**Amt. Imdar® (ppb)**
Bog Brook 1	0	No Test
Bog Brook 2	0	0.11
Bog Brook 3	0	No Test
Pork Brook NW	0.46	No Test
Pork Brook SE	0.97	No Test

Water Withdrawal

Blueberries require more water than rainfall can provide at certain points during the growing season, so most growers tend to irrigate their fields. During early spring, irrigation water is initially used to protect against frost damage, while irrigation later during the summer months is often helpful for good fruit set and adequate growth. Approximately 1” of water per week may be applied during these times. On the Narraguagus River watershed, Wymans Foods irrigates 25% of their blueberry fields, with a goal of irrigating two-thirds in the next 20 years (NRWC, 2003). This increased irrigation could add quite a great deal of stress, particularly during dry years, to the river, its tributaries, and groundwater sources. By extension, this increased irrigation could impact Atlantic salmon as well. Due to concerns over the negative affects of water withdrawal on aquatic ecosystems, the DEP is consulting stakeholders and is creating rules regulating agricultural and other water withdrawals.

According to the Draft Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic salmon (*Salmo salar*) released in June 2004 by the National Marine Fisheries service and the US Fish and Wildlife Service, water withdrawal is listed as a major threat to the survival of Atlantic salmon. Lower stream flows that result from water withdrawal can affect both salmon egg incubation and later growth stages. While high winter and pre-hatch spring flow over salmon redds is necessary for egg survival, high flow is also necessary for proper parr habitat in the summer. Adults require higher fall flow to return to spawning grounds and smolt emigration is likely tied to water flow cues, in addition to day length and water temperature (USFWS/NMFS, 2004). Lower water flows may also result in increased water temperature, affecting the food supply of salmon and the overall health of the aquatic ecosystem.

Water withdrawal from Downeast rivers and streams, utilized for blueberry irrigation, was once a much more prevalent practice than it is now. Currently, only 500 acres of wild blueberries on smaller operations are irrigated with water withdrawn from these rivers (Dalton and Criner, 2000) while larger growers rely on groundwater sources (USFWS/NMFS, 2004). Alternative sources of irrigation water, including withdrawal from wells and aquifers, likely affect ground and surface water hydrology. For example, groundwater extraction may decrease the recharge of spring water into first-order streams that, due to its cool temperature, is key to salmon survival (USFWS/NMFS, 2004).

In 2002, the Maine Department of Environmental Protection proposed that several stretches of the Downeast rivers that host endangered Atlantic salmon (Dennys, East Machias, Machias, Narraguagus, and the Pleasant) be upgraded to AA classification and stretches of the St. Croix river be upgraded to B classification. The AA classification is the highest level of quality and is applied to “outstanding natural resources” (MDEP website). Rivers and streams with this classification must be “free flowing and natural” (MDEP website). The exact meaning of this classification is contentious: the blueberry industry claims that this would restrict impoundments and withdrawals and the DEP maintains that only dams are restricted. The Wild Blueberry Commission opposed this reclassification, on the grounds that flow standards had not yet been established for these rivers and that the reclassification may eliminate or severely limit the irrigation allowed by the blueberry industry.

Irrigation by the blueberry industry is self-regulated. Growers only need a permit to withdraw over 20,000 gallons per day or one percent of low flow volume of a watershed larger than 75 acres estimated to occur for seven days averaged over 10 years. Large-scale, permitted withdrawals are also subject to reporting to the Maine Department of Environmental Protection, in conjuction with the Maine Department of Agricultural, Food, and Rural Resources. Water withdrawals are subject to certain flow conditions as well. During the drought of 1998, water withdrawal by Cherryfield Foods from the Pleasant River were barred when flow dropped below 23 cubic feet per second in the river.

Current research is being conducted by the University of Maine and the USDA to determine the water needs of the plants and to apply irrigation water more efficiently. This effort coincides with the DEP’s rulemaking around water withdrawal. Final rules and legislative action on those withdrawal rules is expected in late 2006 or early 2007.

Processing and Wastewater Discharges

Most water pollution from the blueberry industry is indirect, from fertilizers and pesticides applied to fields. However, blueberry processing may contribute to point source pollution to the rivers in the form of heat pollution and water with a low dissolved oxygen content. The blueberry processors are required by law to have discharge permits and are regulated by the Maine Department of Environmental Protection (DEP). The permits allow certain amounts of water to be withdrawn and returned for certain processes. For example, Jasper Wyman and Sons has a permit to discharge 0.1 million gallons per day (MGD) of process water, 0.27 MGD of "non-contact cooling" water, and 3000 gallons per day of sanitary wastewater into the Narraguagus River from their plant in Cherryfield (MDEP BLWQ, 2004). Cherryfield Foods has a comparable permit with similar discharge amounts. The discharge from blueberry processing may be a higher temperature than the river it is discharged into, up to 26º C (79º F) into the Narraguagus River and up to 32º C (90º F) into the Machias River (USFWS/NMFS,1999). The upstream and downstream migrations of Atlantic salmon may be affected by zones of exceedingly warm water; salmon spend extra energy attempting to swim around these zones (Ewing, 1999). Processors are also allowed to spray limited amounts of processed (clean) waste water as irrigation, or surface application.

During the first quarter of 2003, Jasper Wyman and Sons was found in "significant noncompliance" with its wastewater discharge permit by the DEP for biological oxygen demand, or BOD, violations that occurred during its canning operations (MDEP BLWQ 2004). Biological oxygen demand measures the amount of oxygen that microbes use in breaking down organic matter in water; the higher the BOD, the more oxygen is used and lower dissolved oxygen content results. These zones of low dissolved oxygen (hypoxic conditions), or no dissolved oxygen (anoxic conditions), are detrimental to ecosystem function and may also interfere with downstream and upstream salmon migration.

Sulfur Applications

Precipitation in Maine is naturally acidic, with a pH as low as 4.0. Due to the geologic history of the region, Maine rivers and streams have naturally low buffering capacity that would prevent pH fluctuations and maintain higher pH values despite acidic precipitation (Haines, 1981). Lower pH can be problematic for salmon, having direct impacts on physiology and indirect effects on water chemistry. The minimum pH that causes mortality for each stage is difficult to determine. For eggs and fry, pH 4 (Haines, 1981) to 5 (NAS 2004) is toxic; for parr (or fingerlings) and smolt, this value ranges between 4.5 (Haines, 1981) and 4.6 (NAS, 2004). Lowering the pH from 4.92 to 4.64 reduced the egg survival from 78% to only 46%, with observed delays in hatching as well (Mills, 1989). Lower pH affects reproduction, gill performance, respiration, and osmoregulation of all salmon life stages (Mills, 1989). Exposure to even short-term dips in pH can cause mortality (NAS, 2004). The pH decreases during snow melt in the spring; this coincides with the time that smoltification begins in parr and fry emerge from the stream bottoms, two processes that are susceptible to low pH (USFWS/NMFS, 1999). Indirect effects of lower pH on Atlantic salmon include mobilization of toxic aluminum in low pH soils and waters (NAS 2004).

Wild blueberries are tolerant to lower pH soils; sulfur is often applied to blueberry fields to lower the pH, thus favoring blueberry plants over other plants. The exact amount of sulfur applied to these areas in any given year is not well documented (Dave Yarborough, personal communication), but could potentially exacerbate already low pH levels in nearby rivers. This dynamic is exacerbated by the acidic rainfall that Maine receives, a by-product largely produced by air pollution from industry in neighboring states. Ultimately, acid rain is a contributing concern for Atlantic salmon and the blueberry industry as well. Although the increasingly acidic soil is beneficial to blueberry plants, the combined effect of the acid rain with blueberry cultivation might necessitate action under the ESA. Between further cutting power plant sulfur pollution and restricting sulfur application in blueberry cultivation, it may be simpler and more politically viable to restrict blueberry cultivation. The DEP monitors pH in rivers and streams reasonably well throughout the Downeast region. Examination of water quality data compiled by the DEP revealed that most pH values for the Downeast rivers remained above 5.0, with few exceptions – namely downstream from the Denbo Heath Plant on the Narraguagus River. The DEP should continue to monitor pH levels in various habitats, particularly during susceptible salmon life stages.

Conclusion

Many aspects of blueberry cultivation are in conflict with the preservation of Atlantic salmon. Pesticide use, soil treatments and the redirection of water sources for the cultivation of blueberries have a negative impact on the water quality that is central to the health and survival of Atlantic salmon. Indeed, the conditions under which blueberries thrive – acidic soils, augmented water supplies, elimination of other plant competition and killing insects – result in river conditions that threaten Atlantic salmon health.

Perhaps the largest obstacle to determining the impact of wild blueberry cultivation on endangered Atlantic salmon populations is lack of data. We are left to speculate about possible dangers without having the information needed to accurately assess these threats. Regardless, the blueberry industry has a legal obligation, along with other industries and agencies, to help protect the endangered Atlantic salmon.

Policy Recommendations

In order to better understand the effects of the blueberry industry on endangered Atlantic salmon and to mitigate and eliminate the negative affects, we recommend the following policies and actions:

- EPA should require more extensive testing of pesticide toxicity, chronic affects and interactive toxicity of pesticides and inert ingredients as part of registration and establishment of standards;

- BPC should ban aerial spraying and continue to monitor drift from other application methods;

- BPC should restrict or eliminate the use of pesticides that directly or indirectly harm Atlantic salmon;

- DEP should mitigate stormwater sedimentation from low-maintenance roads in and around blueberry fields;

- DEP should monitor nutrient loading and fertilizer applications in Downeast watersheds; and

- DEP should continue with its water withdrawal rulemaking to protect Atlantic salmon and aquatic ecosystems from this practice.

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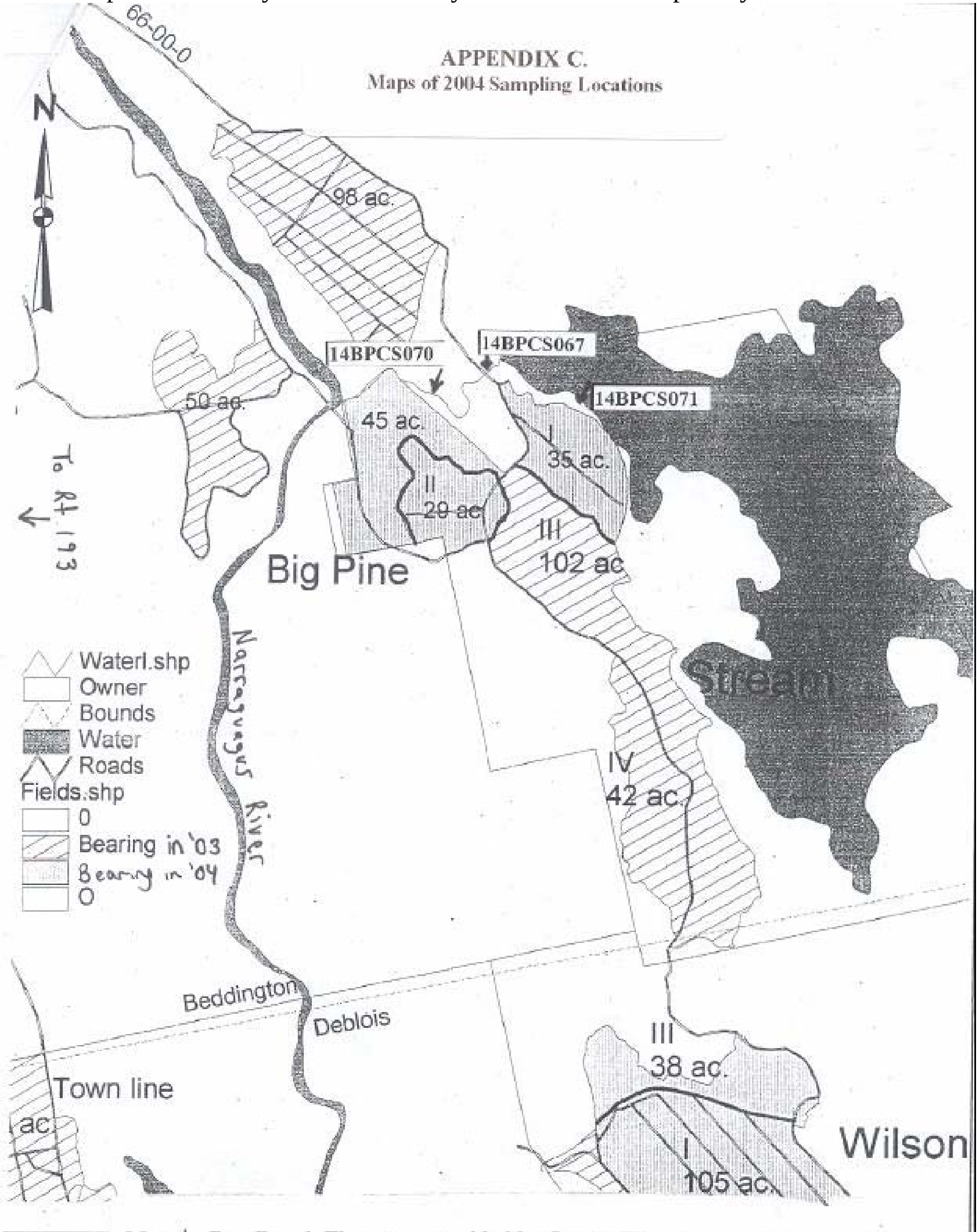
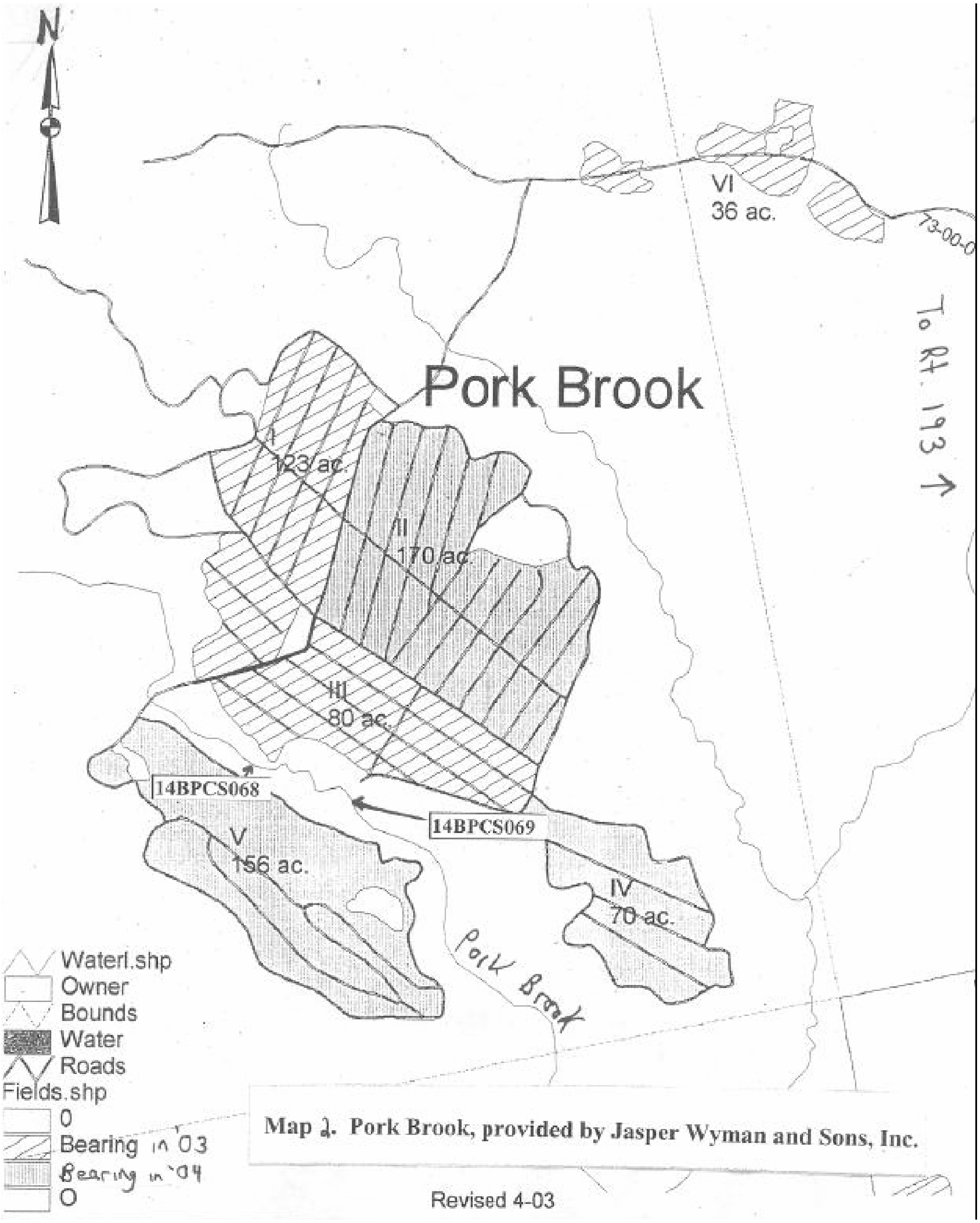
Appendix A

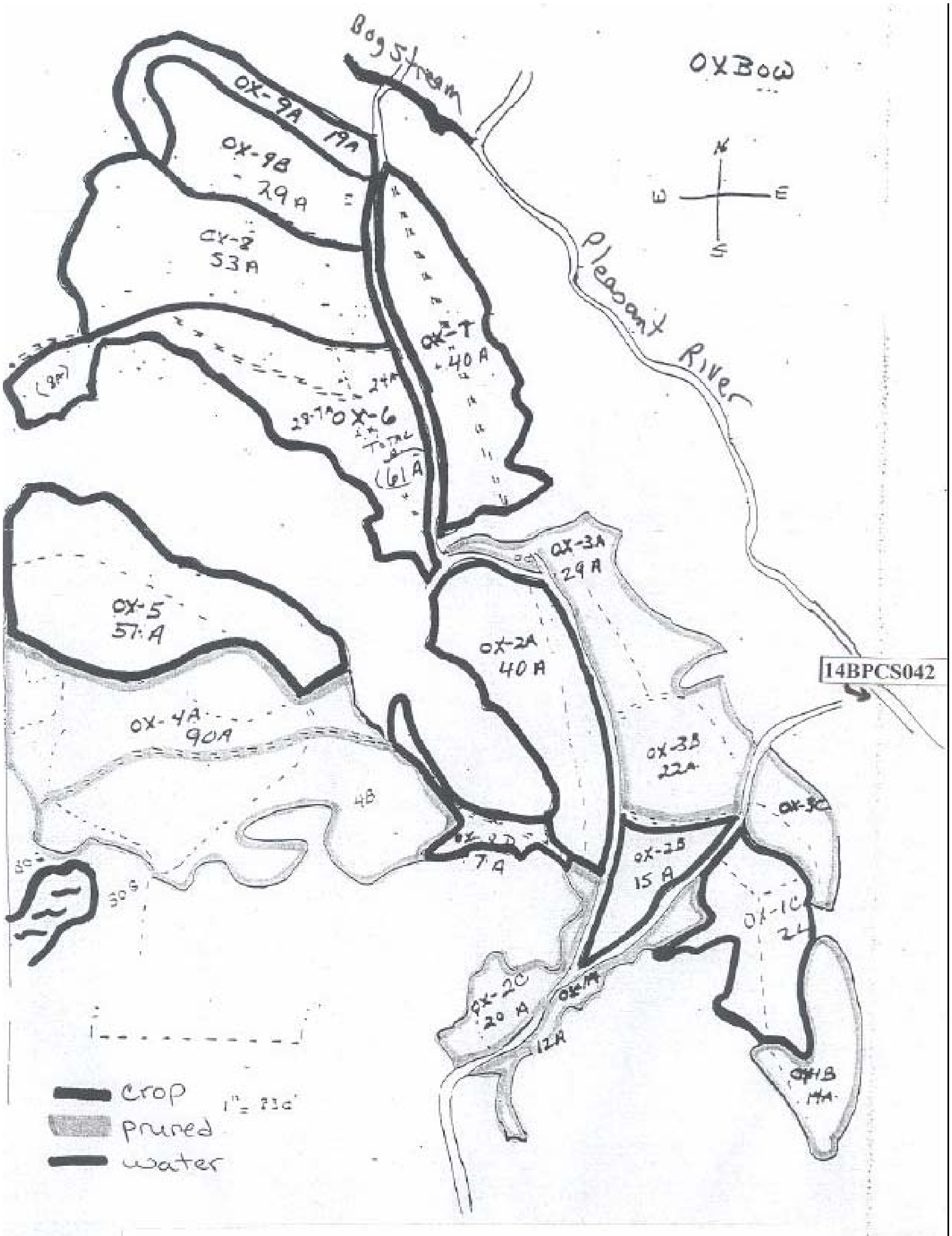
Maps of Blueberry Barrens - Cherryfield Foods and Jasper Wyman and Sons



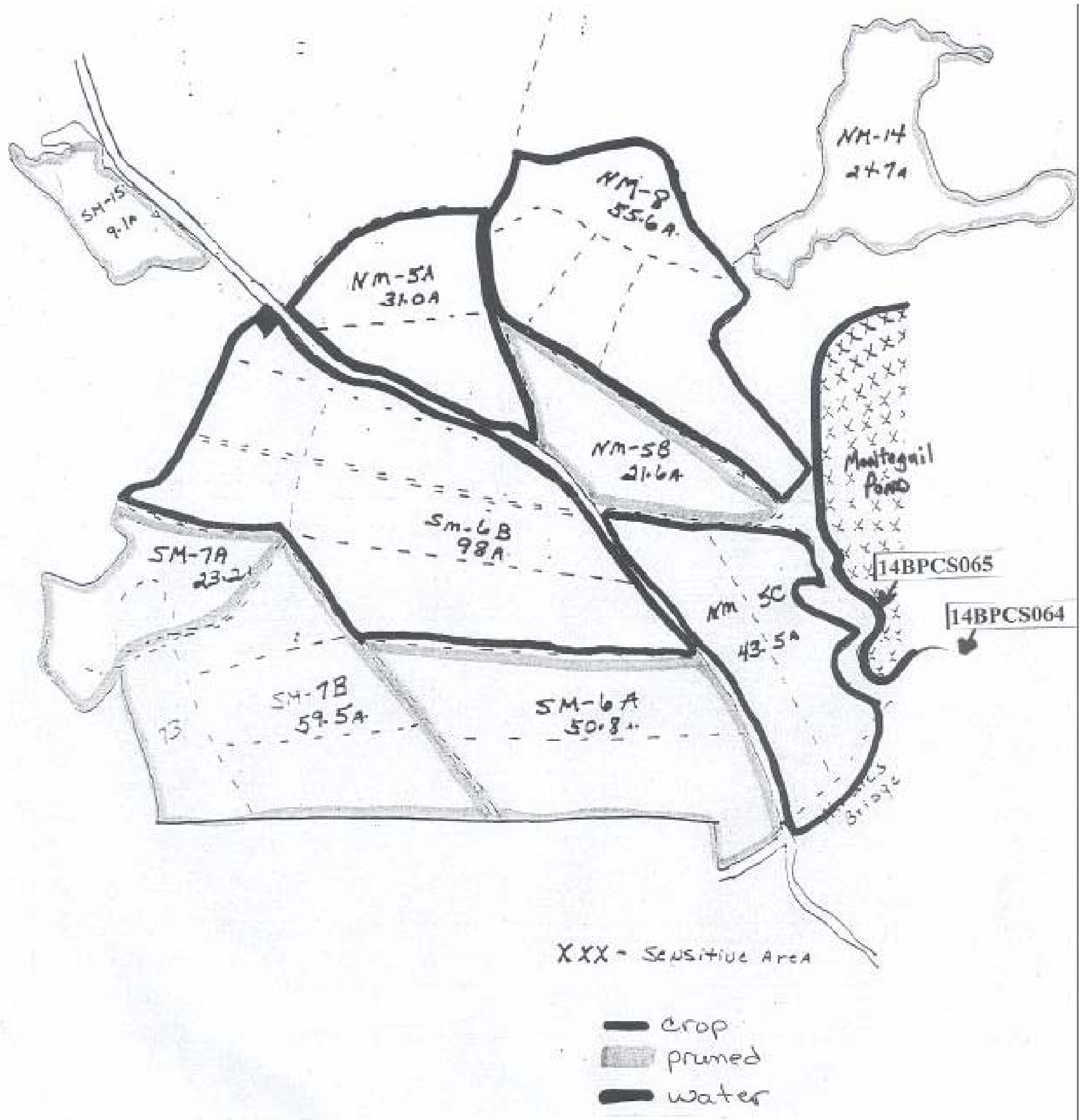
Map 1. Bog Brook Flowage, provided by Jasper Wyman and Sons, Inc.



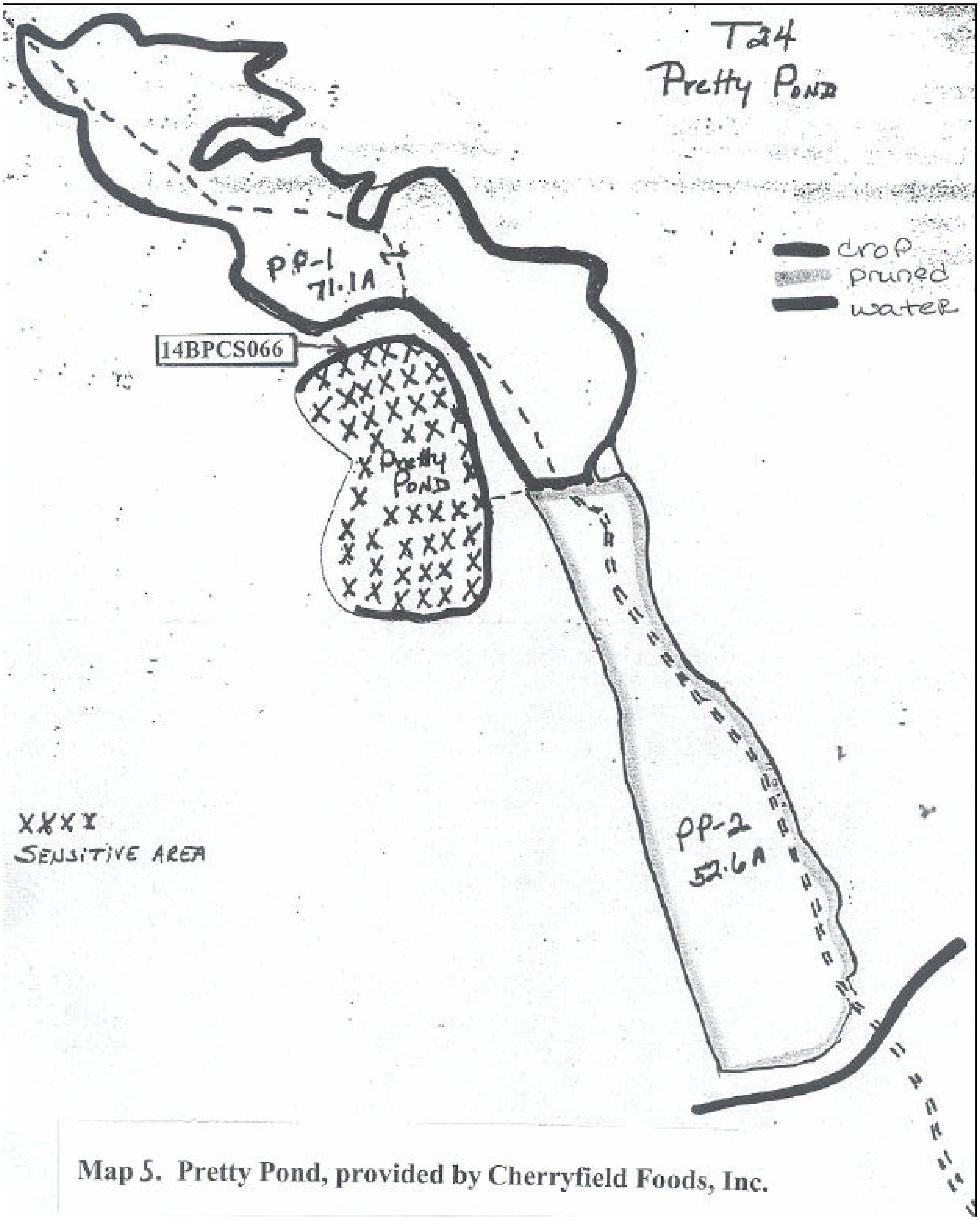
Map 2. Pork Brook, provided by Jasper Wyman and Sons, Inc.



Map 3. Pleasant River, provided by Cherryfield Foods, Inc.



Map 4. Montegail Pond, provided by Cherryfield Foods, Inc.



Map 5. Pretty Pond, provided by Cherryfield Foods, Inc.

All maps courtesy of 2004 Drift Study of Aerially Sprayed Pesticides prepared by Heather Jackson of the Maine Board of Pesticide Control.