CHAPTER NINE: AGRICULTURES AND SILVICULTURE

Croplands, Rangelands, Livestock, and Nursery Operations

Introduction

Substantial portions of croplands, rangelands, and commercial nursery operations are connected, either directly or indirectly, to coastal waters where point and nonpoint pollution can have an adverse effect on aquatic habitats. According to the US Environmental Protection Agency's (US EPA) 2000 National Water Quality Inventory, agriculture was the most widespread source of pollution for assessed rivers and lakes (USEPA 2002a). In that report, agriculture was responsible for 18% of all river-mile impacts and 14% of all lake-acre impacts in the United States. In addition, 48% of all impaired river miles and 41% of all impaired lake acres were attributed to agriculture (USEPA 2002a). Impacts to fishery habitat from agricultural and nursery operations can result from: (1) nutrient loading; (2) introduction of animal wastes; (3) erosion; (4) introduction of salts; (5) pesticides; (6) sedimentation; and (7) suspended silt in water column (USEPA 2002a).

Release of nutrients/eutrophication

Nutrients in agricultural land are found in several different forms and originate from various sources, including: (1) commercial fertilizers containing nitrogen, phosphorus, potassium, secondary nutrients, and micronutrients; (2) manure from animal production facilities; (3) legumes and crop residues; and (4) irrigation water (USEPA 2002a). In addition, agriculturals land are characterized by poorly maintained dirt roads, ditches, and drains that transport sediments and nutrients directly into surface waters. In many instances, headwater streams have been replaced by a constructed system of roads, ditches, and drains that deliver nutrients directly to surface waters (Larimore and Smith 1963). Worldwide, the production of fertilizers is the largest source of anthropogenic nitrogen mobilization, although atmospheric deposition exceeds fertilizer production as the largest nonpoint source of nitrogen to surface waters in the northeastern United States (Howarth et al. 2002). Human activity is estimated to have increased nitrogen input to the coastal water of the northeastern United States, specifically to Chesapeake Bay, MD/VA, by 6- to 8-fold (Howarth et al. 2002). Castro et al. (2003) estimated that the mid-Atlantic and southeast regions contained between 24-37% agricultural lands, with fertilizers and manure applications representing the highest nitrogen sources for those watersheds. The Pamlico Sound-Pungo River, NC, and Chesapeake Bay estuaries contained the highest percent of nitrogen sources coming from agriculture from the mid-Atlantic region (Castro et al. 2003). The second leading cause of pollution in streams and rivers in Pennsylvania has been attributed to agriculture, primarily nutrient loading and siltation (Markham 2006).

Nitrogen and phosphorus are the two major nutrients from agriculture sources which degrade water quality. The main forces controlling nutrient movement from land to water are runoff, soil infiltration, and erosion. Introduction of these nutrients into aquatic systems can promote aquatic plant productivity and decay leading to cultural eutrophication (Waldichuk 1993). Eutrophication can adversely affect the quality and productivity of fishery habitats in rivers, lakes, estuaries, and near-shore, coastal waters. Eutrophication can cause a number of secondary effects, such as increased turbidity and water temperature, accumulation of dead organic material, decreased dissolved oxygen, and the proliferation of aquatic vegetation. Cultural eutrophication has resulted in widespread damage to the ecology of the Chesapeake Bay, causing nuisance algal blooms, loss of productive shellfish and blue crab (*Callinectes sapidus*) habitat, and destruction of submerged aquatic vegetation (SAV) beds (Duda 1985). Nearly 80% of the nutrient loads intothe Chesapeake

Bay can be attributed to nonpoint sources, and agriculture accounted for the majority of those (USEPA 2003b). Agriculture accounts for approximately 40% and 48% of nitrogen and phosphorus loads, respectively, to the Chesapeake Bay (USEPA 2003b). Chronic eutrophication has severely impacted the historically productive recreational and commercial fisheries of the Chesapeake Bay.

While eutrophication generally causes increased growth of aquatic vegetation, it has been shown to be responsible for wide spread losses of SAV in many urbanized estuaries (Deegan and Buchsbaum 2005). By stimulating the growth of macroalgae, such as sea lettuce (*Ulva lactuca*), eutrophication can alter the physical structure of seagrass meadows, such as eelgrass (*Zostera marina*), by decreasing shoot density and reducing the size and depth of beds (Short et al. 1993; MacKenzie 2005). These alterations can result in the destruction of habitat that is critical for developing juvenile fish and can severely impair biological food chains (Hanson et al. 2003).

Groundwater is also susceptible to nutrient contamination in agricultural lands composed of sandy or other coarse-textured soil (USGS 1999). Nitrate, a highly soluble and mobile form of nitrogen, can leach rapidly through the soil profile and accumulate in groundwater, especially in shallow zones (USEPA 2003a). In the eastern United States, nitrogen contamination of groundwater is generally higher in areas that receive excessive applications of agriculture fertilizers and manure, most notably in mid-Atlantic states like Delaware, Maryland, and Virginia (i.e., the Delmarva Peninsula) (USEPA 2003a). When discharged through seeps and drains, or by direct subsurface flow to water bodies, groundwater can be a significant source of nutrients to surface waters (Hanson et al. 2003). Phosphorus from agricultural sources, such as manure and fertilizer applications and tillage, can also be a significant contributor to eutrophication in freshwater and estuarine ecosystems. Cultivation of agricultural land greatly increases erosion and with it the export of particle-bound phosphorus.

Livestock waste (manure), including fecal and urinary wastes of livestock and poultry, processing water and the feed, bedding, litter, and soil with which they become intermixed, is reported to be the single largest source of phosphorus contamination in the United States (Howarth et al. 2002). Because cattle are often allowed to graze in riparian areas, nutrients that are consumed elsewhere are often excreted in riparian zones that can impact adjacent aquatic habitats (Hanson et al. 2003). Because grazing processes remove or disturb riparian vegetation and soils, runoff that carries additional organic wastes and nutrients into aquatic habitats is accelerated (Hanson et al. 2003). Pollutants contained and processed in rangelands, pastures, or confined animal facilities can be transported by storm water runoff into aquatic environments. These pollutants may include oxygen-demanding substances such as nitrogen and phosphorus; organic solids; salts; bacteria, viruses, and other microorganisms; metals; and sediments that increase organic decomposition (USEPA 2003a). Increased nutrient levels resulting from processed water or manure causes excessive aquatic plant growth and algae. The decomposition of aquatic plants depletes dissolved oxygen in the water, creating anoxic or hypoxic conditions that can lead to fish kills. For example, six individual spills from animal waste lagoons in North Carolina during 1995 totaled almost 30 million gallons; including one spill that involved 22 million gallons of swine waste that was responsible for a fish kill along a 19-mile stretch of the New River (USEPA 2003a). Animal wastes from farms in the United States produce nearly 1.5 billion tons of nitrogen and phosphate-laden wastes each year that contribute to nutrient contamination in approximately 27,999 miles of rivers and groundwater (Markham 2006). The release of animal wastes from livestock production facilities have led to reductions in productivity of riverine, estuarine, and marine habitats because of eutrophication.

Introduction of pathogens

Stormwater runoff from agriculture, particularly livestock manure, typically contains elevated levels of pathogens, including bacteria, viruses, and protozoa (USEPA 2003a). Pathogens are generally a concern to human health because of consumption of contaminated shellfish and finfish and exposure at beaches and swimming areas (USEPA 2005). While many pathogens affecting marine organisms are associated with upland runoff of fecal contamination, there are also naturally occurring marine pathogens that affect fish and shellfish (Shumway and Kraeuter 2000). Some naturally occurring pathogens, such as bacteria from the genus, *Vibrio*, or the dinoflagellate, *Pfiesteria*, can produce blooms that release toxins capable of harming fish and possibly human health under certain conditions (Buck et al. 1997; Shumway and Kraeuter 2000). Although the factors leading to the formation of blooms for these species requires additional research, nutrient enrichment of coastal waters is suspected to play a role (Buck et al. 1997). See also the chapter on Introduced/Nuisance Species and Aquaculture for more information on pathogens.

Reduced dissolved oxygen

Reduced (hypoxic) or depleted (anoxic) oxygen conditions within estuarine waters as a result of cultural eutrophication may be one of the most severe problems facing coastal waters in the United States (Deegan and Buchsbaum 2005), and agriculture is a major contributing source in some areas. In general, extensive hypoxia has been more chronic in river-estuarine systems in the southern portion of the northeast coast (i.e., Narragansett Bay, RI, to Chesapeake Bay) than in the northern portion (Whitledge 1985; O'Reilly 1994; NOAA 1997). In 2001 approximately 50% of the deeper waters of the Chesapeake Bay had reduced dissolved oxygen concentrations (USEPA 2003b).

Warm temperatures, high metabolic sediment demand, and water column stratification, conditions that can be common at night during summer months, may lead to low dissolved oxygen concentrations in bottom waters (Deegan and Buchsbaum 2005). Hypoxia in estuaries north of Cape Cod, MA, are uncommon because of strong mixing and flushing characteristics of their waters in the northern New England region. However, high nutrient loads into aquatic habitats from livestock and croplands can cause hypoxic or anoxic conditions that can result in fish kills in rivers and estuaries in other areas of the northeast coast (USEPA 2003a; Deegan and Buchsbaum 2005), and they can potentially alter long-term community dynamics (NRC 2000; Castro et al. 2003). Chronic low-dissolved oxygen conditions can lower the growth and survivorship of finfish and shellfish. For example, the effect of chronic, diurnally fluctuating levels of dissolved oxygen has been shown to reduce the growth of young-of-the-year winter flounder (*Pseudopleuronectes americanus*) (Bejda et al. 1992).

Altered temperature regimes

Increased siltation in shallow aquatic habitats caused by erosion from croplands and livestock operations can result in increased water temperature (Duda 1985). In addition to accelerating bank erosion, loss of riparian vegetation resulting from livestock grazing can increase the amount of solar radiation reaching streams and rivers resulting in an increase in water temperatures (Moring 2005). Altered temperature regimes have the ability to affect the distribution, growth rates, survival, migration patterns, egg maturation and incubation success, competitive ability, and resistance to parasites, diseases, and pollutants of aquatic organisms (USEPA 2003a). The temperature regimes of cold-water fish, such as Atlantic salmon (*Salmo salar*) and rainbow smelt (*Osmerus mordax*), may be exceeded in some rivers and streams of the northeastern United States and lead to local extirpation of these species. The removal of riparian vegetation can also lower water temperatures during winter, which can increase the formation of ice and delay the development of incubating fish eggs and alevins (Hanson et al. 2003). Some evidence indicates that elevated water temperatures in freshwater streams and rivers in the northeastern United States may be responsible for increased algal growth, which has been suggested as a possible factor in the diminished stocks of rainbow smelt (Moring 2005). In the watersheds of eastern Maine, blueberry and cranberry processing plants discharge processing water into rivers important to Atlantic salmon spawning and migration. These facilities are permitted to discharge water at temperatures known to be lethal to both juvenile and adult Atlantic salmon (USFWS and NMFS 1999).

Siltation, sedimentation, and turbidity

As discussed above, siltation, sedimentation, and turbidity impacts related to agricultural activities are generally a result of soil erosion. Agricultural lands are also characterized by poorly maintained dirt roads, ditches, and drains that transport sediments directly into surface waters. Suspended sediments in aquatic environments reduce the availability of sunlight to aquatic plants, cover fish spawning areas and food supply, interfere with filtering capacity of filter feeders, and can clog and harm the gills of fish, and when the sediments settle they can cover oysters and shells which prevents oyster larvae from settling on them (USEPA 2003a; MacKenzie 2007). The largest source of sediment into Chesapeake Bay, for example, is from agriculture. Approximately 63% of the over 5 million pounds of sediment delivered each year to tidal waters of the Chesapeake Bay comes from agricultural sources (MacKenzie 1983; USEPA 2003b) and results in devastating impacts to shellfish and SAV. Wide-spread agricultural deforestation during the 18th and 19th centuries contributed to large sediment loads in the James,VA; York, VA; Rappahannock,VA; Potomac, WV/VA/MD/DC; Patuxent, MD; Choptank, DE/MD; and Nanticoke, DE/MD, Rivers and which may have contributed to the decline of Atlantic sturgeon (*Acipenser oxyrinchus*) populations in the Chesapeake Bay watershed (USFWS and NMFS 1998).

In addition to the affects described in greater detail within the Bank and Soil Erosion subsection of this chapter, contaminants such as pesticides, phosphorus, and ammonium are transported with sediment in an adsorbed state, such that they may not be immediately available to aquatic organisms. However, alteration in water quality, such as decreased oxygen concentration or changes in water alkalinity, may cause these chemicals to be released from the sediment (USEPA 2003a). Consequently, the impacts to aquatic organisms associated with siltation and sedimentation may be combined with the affects of pollution originating from the agricultural lands.

Altered hydrological regimes

There are both direct and indirect affects of agriculture activities on the hydrology of coastal watersheds. Direct alterations of hydrology can occur from water diversion projects used for crop irrigation and livestock operations. The volume and timing of freshwater delivery to estuaries can be altered by water diversions, such as for agriculture, which in turn can increase the salinity of coastal ecosystems and diminish the supply of sediments and nutrients to estuaries (Deegan and Buchsbaum 2005). Agriculture activities use large volumes of water for irrigation, accounting for one-third of all US water withdrawals in 2000 and the second largest source of total water use after thermoelectric energy (Markham 2006).

Water withdrawal for agriculture can have adverse affects on anadromous fish, particularly Atlantic salmon, which use rivers in the Gulf of Maine for spawning and migration. Water withdrawals pose a threat to life stages of Atlantic salmon and their habitat in the Machias, Pleasant, and Narraguagus Rivers in Maine (USFWS and NMFS 1999). Freshwater was diverted from eastern Maine watersheds in the late 1990s to irrigate approximately 6,000 acres of blueberry agricultural activities, and that acreage was expected to double by the year 2005 (USFWS and NMFS 1999). The withdrawal of water may also affect the productivity of oyster beds in the eastern United States, because the distribution of oysters is largely governed by water salinity. When water is withdrawn, oyster beds are forced to move upstream and into smaller areas and often closer to cities where pollution may affect commercial marketing of the oysters (MacKenzie 2007).

Altered hydrology and flood plain storage patterns around estuaries can effect water residence time, temperature, and salinity and can increase vertical stratification of the water column, which inhibits the diffusion of oxygen into deeper water leading to reduced (hypoxic) or depleted (anoxic) dissolved oxygen concentrations (Kennedy et al. 2002). Altered hydrodynamics can affect estuarine circulation, including short-term (diel) and longer term (seasonal or annual) changes (Deegan and Buchsbaum 2005). In addition, counter current flows set up by freshwater discharges into estuaries are important for larvae and juvenile fish entering those estuaries. The diurnal behavioral adaptations of marine and estuarine species allow larvae and early juveniles to concentrate in estuaries. Reductions in freshwater flows caused by increased freshwater withdrawals can disrupt counter current flows and larval transport into estuaries (Deegan and Buchsbaum 2005). The quality and quantity of freshwater flows into estuaries are important in maintaining suitable conditions for spawning, egg, larval, and juvenile development for many estuarine-dependent species.

Indirect affects occur when sediments are transported from agricultural lands via soil erosion and are deposited in roadside ditches, streams, rivers, and navigation channels, which decrease the capacity of watersheds to attenuate the affects of flooding. The morphology of streams and rivers can be altered by eroded soil from improper livestock grazing and croplands, changing the stream width and depth and the timing and magnitude of stream flow (USEPA 2003a). In addition, sediment deposited in lakes and navigation channels reduces the storage capacity of those systems and necessitates more frequent dredging (USEPA 2003a).

Impaired fish passage

Sediments transported from agricultural lands via soil erosion can change the morphology of streams and rivers. As a result, alteration of stream width and depth and the timing and magnitude of stream flow can impair the ability of anadromous fish to reach upstream spawning habitats. Roads that are constructed to access agriculture lands and for livestock may impede or prohibit migrating fish. For example, culverts constructed under roads to allow for water flow can alter the velocity and volume of water in streams and inhibit the ability of fish to migrate through the structure (Furniss et al. 1991). Additional information on fish passage impairments can be reviewed in the Alteration of Freshwater Systems chapter of this report.

Change in community structure and species composition

Cropland and livestock operations can result in community-level impacts to riverine and estuarine ecosystems. As mentioned above, fertilizers applied to agricultural lands enter streams, rivers, and estuaries through stormwater runoff and groundwater sources (e.g., seeps and subsurface flows) and may result in eutrophication. Eutrophication can cause a number of secondary effects, such as increased turbidity and water temperature, accumulation of dead organic material, decreased dissolved oxygen, and the proliferation of macroalgae, such as sea lettuce (MacKenzie 2005). These alterations can then result in the destruction of habitat for small or juvenile fish and severely impair biological food chains (Hanson et al. 2003). For example, eelgrass beds growing in deeper areas of estuaries tend to be impacted more than shallower areas because those beds are very sensitive to light attenuation as a result of eutrophication (Deegan and Buchsbaum 2005). Species that depend upon eelgrass beds may be forced into shallower, potentially less desirable habitats. Declines in commercially and recreationally important finfish in Waquoit Bay, MA, have followed a concomitant decline in eelgrass beds for that area (Deegan and Buchsbaum 2005). Similarly, eelgrass wasting disease was documented to be responsible for severe declines in bay scallop (*Argopectin irradians*) landings along the east coast in the 1930s (Buchsbaum 2005).

Other impacts from agricultural activities such as soil erosion and release of fine sediments can alter aquatic communities through siltation and alteration of benthic substrates. Waldichuk (1993) identified a number of impacts to Pacific salmon (*Oncorhynchus* spp.) caused by activities related to agriculture, such as siltation in spawning, egg incubation and feeding habitats, impaired respiration and abrasion of gills from suspended particles, and failure of egg hatching resulting from low dissolved oxygen. The cumulative effect from the degradation of riverine habitats can inhibit or preclude restoration efforts of salmon populations to historic ranges by altering the community. Release of nutrients from fertilizers applied to croplands, livestock manure, and erosion of soils can reduce the dissolved oxygen levels in aquatic habitats through storm water runoff. Reduced dissolved oxygen in the water or sediments can change community composition to coastal habitats, particularly in areas with restricted water circulation such as coastal ponds, subtidal basins, and salt marsh creeks (Deegan and Buchsbaum 2005). Chronic hypoxia caused by cultural eutrophication can permanently alter the species composition and productivity of these areas.

Entrainment and impingement

Water diverted and extracted for agriculture use can entrain (i.e., draw into flow system) and impinge (i.e., capture onto filter screens) aquatic organisms. Entrainment and impingement generally affects eggs, larvae, and early juvenile fish and invertebrates that cannot actively avoid the currents created at the water intake opening (ASMFC 1992). Long-term water withdrawal may adversely affect fish and invertebrate populations as well as their prey by adding another source of mortality to the early life stage which often determines recruitment and year-class strength (Hanson et al. 2003). Refer to the Physical Affects: Water Intake and Discharge Facilities chapter in this report for additional information on entrainment and impingement.

Bank and soil erosion

Soil erosion in US farmland is estimated to occur seven times as fast as soil formation (Markham 2006). Soil erosion can lead to the transport of fine sediment that may be associated with a wide variety of pollutants from agricultural land into the aquatic environment. The presence of livestock in the riparian zone accelerates sediment transport rates by increasing surface soil erosion (Hanson et al. 2003), loss of vegetation caused by trampling, and streambank erosion resulting from shearing or sloughing (Platts 1991). Increased sedimentation in aquatic systems can increase turbidity and the temperature of the water, reduce light penetration and dissolved oxygen, smother fish spawning areas and food supplies, decrease the growth of SAV, clog the filtering capacity of filter feeders, clog and harm the gills of fish, interfere with feeding behaviors of certain species, cover shells on oyster beds, and significantly lower overall biological productivity (MacKenzie 1983; Duda 1985; USEPA 2003a). Soil eroded and transported from cropland usually contains a higher percentage of finer and less dense particles, which tend to have a higher affinity for adsorbing pollutants such as insecticides, herbicides, trace metals, and nutrients (Duda 1985; USEPA 2003a). One of the consequences of erosional runoff from agricultural land is that it necessitates more frequent dredging of navigational channels (USEPA 2003a), which may result in transportation to and disposal of contaminated sediments in areas important to fisheries production and other marine biota (Witman 1996). Deposition of sediments from erosional runoff can also decrease the storage capacity of roadside ditches, streams, rivers, and navigation channels, resulting in more frequent flooding (USEPA 2003a).

Loss and alteration of riparian-wetland areas

Functioning riparian-wetland areas require stable interactions between geology, soil, water, and vegetation in order to maintain productive riverine ecosystems. When functioning properly, riparian-wetland areas can: (1) reduce erosion and improve water quality by dissipating stream energy; (2) filter sediment and runoff from floodplain development; (3) support denitrification of nitrate-contaminated groundwater; (4) improve floodwater retention and groundwater discharge; (5) develop root masses that stabilize banks from scouring and slumping; (6) develop ponding and channel characteristics necessary to provide habitat for fish, waterfowl, and invertebrates; and (7) support biodiversity (USEPA 2003a). Agriculture activities have the potential to degrade riparian habitats. In particular, improper livestock grazing along riparian corridors can eliminate or reduce vegetation by trampling and increase streambank erosion by shearing or sloughing (Platts 1991). These effects tend to increase the streambank angle, which increases stream width, decreases stream depth, and alters or eliminates fish habitat (USEPA 2003a). As discussed above, the transport of eroded soil from the streambank to streams and rivers impacts water quality and aquatic habitats. Removing riparian vegetation also increases the amount of solar radiation reaching the stream and can result in higher water temperatures.

Reduced soil infiltration and soil compaction

Tillage of croplands aerates the upper soil but tends to compact fine textured soils just below the depth of tillage, thus altering infiltration. Use of farm machinery on cropland and adjacent roads causes further compaction, reducing infiltration and increasing surface runoff (Hanson et al. 2003).

Johnson (1992) and Platts (1991) reviewed studies related to livestock grazing and concluded that heavy grazing nearly always decreases infiltration, reduces vegetative biomass, and increases bare soil. Compaction of rangelands generally increases with grazing intensity, although site-specific soil and vegetative conditions are also important factors in determining the effects of soil compaction (Kauffman and Krueger 1984). Reduced soil infiltration and compaction caused by agriculture are two of the factors that accelerate erosion and release of sediments and contaminants in aquatic habitats.

Salts are present in varying amounts in all soils because of the natural weathering process, but agricultural lands that have poor subsurface drainage can lead to high salt concentrations. Likewise, irrigation water, whether from ground or surface water sources has a natural base load of dissolved mineral salts. Irrigation return flows convey the salt to the receiving streams or groundwater reservoirs. If the amount of salt in the return flow is low in comparison to the total stream flow, water quality may not be degraded to the extent that aquatic functions are impaired. However, if the process of water diversion and the return flow of saline drainage water is repeated many times along a stream or river, downstream habitat quality can become progressively degraded (USEPA 2003a). The accumulation of salts, particularly on irrigated croplands, tends to cause soil dispersion, structure breakdown, and decreased infiltration (USEPA 2003a). While salts are generally a greater pollutant for freshwater ecosystems than for estuarine systems, they may adversely affect anadromous fish that depend upon freshwater systems for crucial portions of their life cycles (USEPA 2003a).

Land-use change (post-agriculture)

When demands for developable land are sufficiently high, the value of land in developed use will exceed its value in agricultural use. In general, conversion of land from agricultural to urban uses is largely irreversible according to the US Department of Agriculture. In the continental United States, census data from urban areas have shown more than a doubling of agricultural land conversion from 25.5 million acres to 55.9 million acres between 1960 and 1990 (USDA 2005). While impacts on aquatic ecosystems from agriculture may be problematic in some areas, conversion of croplands and rangelands to urban and industrial uses may be more harmful in the long-term. Between 1992 and 1997 the state of New York lost approximately 90,000 acres of prime farmland to residential and commercial development, which was 140% faster than in the previous five years (Markham 2006). Refer to the Coastal Development chapter in this report for more information on the impacts of land-use change.

Release of pesticides, herbicides, and fungicides

The term “pesticide” is a collective description of hundreds of chemicals used to protect crops from damaging organisms with different sources and fates in the aquatic environment and that have varying toxic effects on fish and other aquatic organisms (USEPA 2003a). Pesticides can be divided into four categories according to the target pest: insecticides, herbicides, fungicides, and nematicides (USEPA 2003a). Agricultural activities are a major nonpoint source of pesticide pollution in coastal ecosystems (Hanson et al. 2003). Large quantities of pesticides, perhaps 18-20 pounds of pesticide active ingredient per acre, are applied to vegetable crops in coastal areas to control insect and plant pests (Scott et al. 1999). Soil eroded and transported from croplands and rangelands usually contains a higher percentage of finer and less dense particles, which tend to have a higher affinity for adsorbing pollutants such as insecticides and herbicides (Duda 1985; USEPA 2003a). In addition, agricultural lands are typically characterized by poorly maintained dirt roads, ditches and drains that transport sediments, nutrients, and pesticides directly into surface waters. In many instances, roads, ditches, and drains have replaced headwater streams, and these constructed systems deliver pollutants directly to surface waters (Larimore and Smith 1963). Pesticides are frequently detected in freshwater and estuarine systems that provide fishery habitat.

The most common pesticides include insecticides, herbicides, and fungicides. These are used for pest control on forested lands, agricultural crops, tree farms, and nurseries. Pesticides can enter the aquatic environment as single chemicals or complex mixtures. Direct applications, surface runoff, aerial drift, leaching, agricultural return flows, and groundwater intrusions are all examples of transport processes that deliver pesticides to aquatic ecosystems (Hanson et al. 2003).

Most studies evaluating pesticides in runoff and streams generally find that concentrations can be relatively high near the application site and soon after application but are significantly reduced further downstream and with time (USEPA 2003a). However, some pesticides used in the past, such as dichlorodiphenyl trichloroethane (DDT), are known to persist in the environment for years after application. Chlorinated pesticides, such as DDT, and some of the breakdown products are known to cause malformation and fatality in eggs and larvae, alter respiration, and disrupt central nervous system functions in fish (Gould et al. 1994). In addition, pesticides containing organochlorine compounds accumulate and persist in the fatty tissue and livers of fish and could be a threat to human health for those who consume contaminated fish (Gould et al. 1994).

Pesticides may bioaccumulate in organisms by first being adsorbed by sediments and detritus which are ingested by zooplankton and then eaten by planktivores, which in turn are eaten by fish (ASMFC 1992). For example, the livers of winter flounder from Boston and Salem Harbors, MA, contained the highest concentrations of DDT found on the east coast of the United

States and were ranked first and third, respectively, in the country in terms of total pesticides (Larsen 1992). In the Pocomoke River, MD/DE, a tributary of the Chesapeake Bay, agricultural runoff (primarily from poultry farms) was identified as one of the major sources of contaminants (Karuppiah and Gupta 1996). Blueberry and cranberry agriculture is an important land use in eastern Maine watersheds and involves the use of a number of pesticides, herbicides, and fungicides that may cause immediate mortalities to juvenile Atlantic salmon or can have indirect effects when chemicals enter rivers (USFWS and NMFS 1999). One study investigating the effects of two different classes of pesticides (organochlorines and organophosphates) in South Carolina estuaries found significant affects on populations of the dominant macrofauna species, daggerblade grass shrimp (*Palaemonetes pugio*), and mummichogs (*Fundulus heteroclitus*) (Scott et al. 1999). The study found impacts from pesticide runoff on daggerblade grass shrimp populations may cause community-level disruptions in estuaries; however, the authors concluded that implementation of integrated pest management, best management practices, and retention ponds could significantly reduce the levels of nonpoint source runoff from agriculture (Scott et al. 1999).

Endocrine disruptors

Studies have recently focused on a group of chemicals, called "endocrine disruptors," that when present at extremely low concentrates can interfere with fish endocrine systems. Some of these chemicals act as "environmental hormones" that may mimic the function of the sex hormones androgen and estrogen (Thurberg and Gould 2005). Some of the chemicals shown to be estrogenic include some polychlorinated biphenyl (PCB) congeners, dieldrin, DDT, phthalates and alkylphenols (Thurberg and Gould 2005), which have had or still have applications in agriculture. Several studies have found vitellogenin, a yolk precursor protein, in male fish in the North Sea estuaries (Thurberg and Gould 2005). Metals have also been implicated in disrupting endocrine secretions of marine organisms, potentially disrupting natural biotic processes (Brodeur et al. 1997). However, the long-term effect of endocrine-disrupting substances on aquatic life is not well understood and demands serious attention by the scientific and resource policy communities.

Conservation measures and best management practices for croplands, rangelands, livestock, and nursery operations (adapted from Hanson et al. 2003)

1. Recommend field and landscape buffers to provide cost-effective protection against the cumulative effects of multiple pollutant discharges associated with agricultural activities, including riparian forests, alley cropping, contour buffer strips, crosswind trap strips, field borders, filter strips, grassed waterways with vegetative filters, herbaceous wind barriers, vegetative barriers, and windbreak/shelterbelts.
2. Protect and restore soil quality with natural controls that affect permeability and water holding capacity, nutrient availability, organic matter content, and biological activity of the soil. Some examples of best management practices include cover cropping, crop sequence, sediment basins, contour farming, conservation tillage, crop residue management, grazing management, and the use of low-impact farming equipment.
3. Promote efficient use and appropriate applications of pesticides and irrigated water. Sound agricultural practices include use of integrated pest management, irrigation management, soil testing, and appropriate timing of nutrient applications.
4. Encourage protection and restoration of rangelands with practices such as rotational grazing systems or livestock distribution controls, exclusion of livestock from riparian and aquatic areas,

livestock-specific erosion controls, reestablishment of vegetation, or extensive brush management correction.

5. Avoid locating new confined animal facilities or expansion of existing facilities near riparian habitat, surface waters, and areas with high leaching potential to surface or groundwater. Ensure that adequate nutrient and wastewater collection facilities are in place.
6. Minimize water withdrawals for irrigation and promote water conservation measures, such as water reuse.
7. Site roads for agricultural lands to avoid sensitive areas such as streams, wetlands, and steep slopes.
8. Include best management practices (BMPs) for agricultural road construction plans, including erosion control, avoidance of side casting of road materials into streams, and using only native vegetation in stabilization plantings.
9. Use seasonal restrictions to avoid impacts to habitat during species' critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

Silviculture and Timber Harvest Activities

Introduction

The growth and harvest of forestry products are major land-use types for watersheds along the east coast, particularly in New England, and can have short-term and long-term impacts to riverine habitat (USFWS and NMFS 1999). Forestry is the dominant land-use type in the watersheds of the Dennys, East Machias, Machias, Pleasant, and Narraguagus Rivers in Maine (USFWS and NMFS 1999). Forests that once covered up to 95% of the Chesapeake Bay watershed now cover only 58%, primarily because of land clearing for agriculture and timber (USEPA 2003b). Timber harvest generally removes the dominant vegetation; converts mature and old-growth upland and riparian forests to tree stands or forests of early seral stage; reduces the permeability of soils; increases sedimentation from surface runoff and mass wasting processes; alters hydrologic regimes; and impairs fish passage through inadequate design, construction, and maintenance of stream crossings (Hanson et al. 2003). Silviculture practices can also increase water temperatures in streams and rivers, increase impervious surfaces, and decrease water retention capacity in watersheds (USFWS and NMFS 1999). These watershed changes may result in inadequate river flows; increase stream bank and streambed erosion; sedimentation and siltation of riparian and stream habitat; increase the amount of woody debris; and increase of run-off and associated contaminants (e.g., from herbicides) (Sigman 1985; Hicks et al. 1991; Hanson et al. 2003). Debris (i.e., wood and silt) is released into the water as a result of timber harvest activities and can smother benthic habitat. Poorly placed or designed road construction can cause erosion, producing additional silt and sediment that can impact stream and riparian habitat. Deforestation can alter or impair natural habitat structures and dynamics of the ecosystem.

Four major categories of silviculture activities that can impact fishery habitat are: (1) construction of logging roads; (2) creation of barriers; (3) removal of streamside vegetation; and (4) input of pesticide and herbicide treatments to aquatic habitats.

Release of nutrients/eutrophication

After logging activities, concentrations of plant nutrients in streams and rivers may increase for several years and up to a decade (Hicks et al. 1991). Excess nutrients, combined with increased light regimes caused by the removal of riparian vegetation, can stimulate algal growth; however, the effects of nutrient increases on salmonid populations are not well understood (Hicks et al. 1991). An estimated 41.5 million pounds of nitrogen per year from silviculture activities alone are released into the Chesapeake Bay watershed, contributing to phytoplankton blooms, chronic hypoxia (low dissolved oxygen concentrations), and die-off of SAV (USEPA 2003b).

Reduced dissolved oxygen

Small wood debris and silt resulting from timber harvesting can smother benthic habitat and reduce dissolved oxygen levels in streams (Hicks et al. 1991; Hanson et al. 2003). Fine organic material introduced into streams following logging can result in increased oxygen demand and reduced exchange of surface and intergravel water (Hicks et al. 1991). While low oxygen conditions may not directly kill salmon embryos and alevins in streams after logging, emergent juveniles may have reduced viability (Hicks et al. 1991). Introduction of nutrients into aquatic systems can promote aquatic plant productivity and decay leading to cultural eutrophication (Waldichuk 1993). Anoxic (without oxygen) or hypoxic (low oxygen) conditions have caused widespread ecological problems for the Chesapeake Bay, resulting in a variety ecosystem impacts including the loss of shellfish beds and reductions of fish stocks in the Bay (USEPA 2003b). According to Chesapeake Bay Program modeling, approximately 15% of the nitrogen loads entering the Chesapeake Bay watershed each year are from forestry activities (USEPA 2003b).

Altered temperature regimes

Removing streamside vegetation to construct logging access roads and logging adjacent to streams or rivers increase the amount of solar radiation reaching the water body and can increase water temperatures (Beschta et al. 1987; Hicks et al. 1991). In studies conducted in Alaska, researchers found that maximum temperatures in logged streams without riparian buffers exceeded that of unlogged streams by up to 5ºC, but did not reach lethal temperatures (Hanson et al. 2003). In cold climates, the removal of riparian vegetation can result in lower water temperatures during winter, increasing the formation of ice and damaging and delaying the development of incubating fish eggs and alevins (Hanson et al. 2003). In freshwater habitats of the northeastern United States, the temperature tolerances of cold-water fish such as Atlantic salmon and rainbow smelt may be exceeded leading to local extirpation of the species (USFWS and NMFS 1999). However, increased water temperatures can also increase primary and secondary production, which may lead to greater availability of food for fish (Hicks et al. 1991).

Siltation, sedimentation, and turbidity

Sedimentation in streams resulting from timber harvesting activities can reduce benthic community production, cause mortality of incubating salmon eggs and alevins, reduce the amount of habitat available for juvenile salmon, and lower the productivity of oyster beds (MacKenzie 1983; Hicks et al. 1991; Hanson et al. 2003). Fine sediments deposited in salmon spawning gravel can reduce interstitial water flow, causing reduced dissolved oxygen concentrations, and they can physically trap emerging fry in the gravel (Hicks et al. 1991). Fine sediments on stream bottoms and in suspension can also reduce primary production and invertebrate abundance, reducing the availability of prey for fish (Hicks et al. 1991). Sedimentation in riparian habitat resulting from logging activities can reduce streamside vegetation that impacts bank stabilization, increasing solar radiation reaching the stream. In addition, suspended sediments can alter the behavior and feeding efficiencies of salmonids following timber harvesting (Hicks et al. 1991). Sawdust and pulp from sawmills and lumber companies can also enter streams and rivers and adversely affect benthic habitats of anadromous fish (Moring 2005).

Deforestation and silviculture activities have contributed to excessive amounts of sediments in Chesapeake Bay, which have led to adverse affects on benthic communities like SAV, oysters, and clams (USEPA 2003b). Nearly 1 million tons of sediments are estimated to enter the Chesapeake Bay each year from forestry activities alone, which accounts for approximately 20% of the total sediment loads into the Bay (USEPA 2003b).

Bank and soil erosion and altered hydrological regimes

Timber harvesting may result in inadequate or excessive surface and stream flows, increased stream bank and streambed erosion, and the loss of complex instream habitats. Clear cutting large areas of forests can alter the hydrologic characteristics of watersheds, such as water temperature, and result in greater seasonal and daily variation in stream discharge and flows (Hicks et al. 1991; Hanson et al. 2003).

In addition, logging road construction can destabilize slopes and increase erosion and sedimentation. Mass wasting and surface erosion are the two major types of erosion that can occur from logging road construction. Mass movement of soils, commonly referred to as landslides or debris slides, is associated with timber harvesting and road building on high hazard soils and unstable slopes. The result is increased erosion and sediment deposition in down-slope waterways. Erosion from roadways is most severe when poor construction practices are employed that do not include properly located, designed, and installed culverts or when proper ditching is not utilized (Furniss et al. 1991).

Altered hydrology and flood plain storage patterns around estuaries can effect water residence time, temperature, and salinity and can increase vertical stratification of the water column which inhibits the diffusion of oxygen into deeper water leading to reduced (hypoxic) or depleted (anoxic) dissolved oxygen concentrations (Kennedy et al. 2002).

Alteration and loss of vegetation

By removing vegetation, timber harvesting tends to decrease the absorptive capability of the groundcover vegetation. This, in turn, increases surface runoff during periods of high precipitation. These effects can destabilize slopes, increase erosion, and cause sedimentation and debris input to streams (Hanson et al. 2003). Reductions in the supply of large woody debris to streams can result when old-growth forests are removed, with resulting loss of habitat complexity that is important for successful salmonid spawning and rearing (Hicks et al. 1991; Hanson et al. 2003). Removing riparian vegetation increases the amount of solar radiation reaching the stream and can result in higher water temperatures during summer months. A loss of riparian vegetation can also reduce stream water temperatures during the winter months (Beschta et al. 1987; Hicks et al. 1991).

Impaired fish passage

Poorly placed or ill-designed culverts placed as part of road construction can negatively affect access to riverine habitat by fish. Stream crossings (e.g., bridges and culverts) on forest roads are often inadequately designed, installed, and maintained, and they frequently result in full or partial barriers to both the upstream and downsteam migration of adult and juvenile fish (Hanson et al. 2003). Perched culverts, in which the culvert invert at the downstream end is above the water level of the downstream pool, create waterfalls that can be physical barriers to migrating fish. Undersized culverts can accelerate stream flows to the point that these structures become velocity barriers for migrating fish. Blocked culverts can result in displacement of the stream from the downstream channel to the roadway or roadside ditch (Hanson et al. 2003). Blocked culverts often result from installation of undersized culverts or inadequate maintenance to remove debris. In addition, culverts and bridges deteriorate structurally over time, and failure to replace or remove them at the end of their useful life may cause partial or total blockage of fish passage.

Release of pesticides, herbicides, and fungicides

Riparian vegetation is an important component of rearing habitat for fish, providing shade for maintaining cool water temperatures, food supply, channel stability, and structure (Furniss et al. 1991). Herbicides that are used to suppress terrestrial vegetation can negatively impact these habitat functions (USFWS and NMFS 1999). In addition, insecticides applied to forests to control pests can interfere with the smoltification process of Atlantic salmon, preventing some fish from successfully making the transition from fresh to salt water. Matacil, one pesticide used in the Maine timber industry, is known to contain an endocrine disrupting chemical (USFWS and NMFS 1999). These chemicals act as “environmental hormones” that may mimic the function of the sex hormones androgen and estrogen (Thurberg and Gould 2005). Refer to the Chemical Effects: Water Discharge Facilities chapter for more information on endocrine disruptors. Other possible affects to Atlantic salmon from pesticides may include altered chemical perception of home stream odor and osmoregulatory ability (USFWS and NMFS 1999).

Conservation measures and best management practices for silviculture and timber harvest activities

1. Encourage timber operations to be located as far from aquatic habitats as possible. Buffer zones of 100 ft for first- and second-order streams and greater than 600 feet for fourth- and fifth-order streams are recommended.
2. Ensure that all silviculture and timber operations incorporate conservation plans that include control of nonpoint source pollution, protecting important habitat through landowner agreements, maintaining riparian corridors, and monitoring and controlling pesticide use.
3. Incorporate watershed analysis into timber and silviculture projects. Attention should be given to the cumulative effects of past, present, and future timber sales within a watershed.
4. Logging roads should be sited to avoid sensitive areas such as streams, wetlands, and steep slopes.
5. Include BMPs for timber forest road construction plans, including erosion control, avoidance of side casting of road materials into streams, and using only native vegetation in stabilization plantings.
6. Use seasonal restrictions to avoid impacts to habitat during species’ critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

Timber and Paper Mill Processing Activities

Introduction

Timber and paper mill processing activities can affect riverine and estuarine habitats through both chemical and physical means. Timber and lumber processing can release sawdust and wood chips in riverine and estuarine environments where they may impact the water column and benthic habitat of fish and invertebrates. These facilities may also either directly or indirectly release contaminants, such as tannins and lignin products, into aquatic habitats (USFWS and NMFS 1999). Pulp manufacturing converts wood chips or recycled paper products into individual fibers by chemical and/or mechanical means, which are then used to produce various paper products. Paper and pulp mills use and can release a number of chemicals that are toxic to aquatic organisms, including chlorine, dioxins, and acids (Mercer et al. 1997), although a number of these chemicals have been reduced or eliminated from the effluent stream by increased regulations regarding their use.

Chemical contaminant releases

Approximately 80% of all US pulp tonnage comes from kraft or sulfate pulping which uses sodium-based alkaline solutions, such as sodium sulfide and sodium hydroxide (USEPA 2002b). Kraft pulping reportedly involves less release of toxic chemicals, compared to other processes such as sulfite pulping (USEPA 2002b). Paper and pulp mills may also release a number of toxic chemicals used in the process of bleaching pulp for printing and wrapping paper products. The bleaching process may use chlorine, sulfur derivatives, dioxins, furans, resin acids, and other chemicals that are known to be toxic to aquatic organisms (Mercer et al. 1997). These chemicals have been implicated in various abnormalities in fish, including skin and organ tissue lesions, fin necrosis, gill hyperplasia, elevated detoxifying enzymes, impaired liver functions, skeletal deformities, increased incidence of parasites, disruption of the immune system, presence of tumors, and impaired growth and reproduction (Barker et al. 1994; Mercer et al. 1997). Because of concern about the release of dioxins and other contaminants, considerable improvements in the bleaching process have reduced or eliminated the use of elemental chlorine. Approximately 96% of all bleached pulp production uses chlorine-free bleaching technologies (USEPA 2002b).

An endocrine disrupting chemical, 4-nonylphenol, has been used in pulp and paper mill plants in Maine and has been shown to interfere with smoltification processes and the chemical perception of home range, and osmoregulatory ability in Atlantic salmon (USFWS and NMFS 1999). Other studies have implicated pulp and paper effluents in altered egg production, gonad development, sex steroids, secondary sexual characteristics, and vitellogenin concentration in male fish, which is considered to be an indicator of estrogenicity (Kovacs et al. 2005). A study investigating the prevalence of a microsporan parasite found in winter flounder in Newfoundland (Canada) waters observed infestations in the liver, kidney, spleen, heart, and gonads of fish collected downstream from pulp and paper mills, whereas fish collected from pristine sites harbored cysts of the parasite in only the digestive wall (Khan 2004). In addition, flounder with a high prevalence of parasite infections throughout multiple organs were found to have significant impairments to growth, organ mass, reproduction, and survival that were not observed in fish sampled from pristine locations, suggesting a link between those affects and effluent discharged by the pulp and paper mills (Khan 2004).

Entrainment and impingement

Pulp and paper mills require large amounts of water and energy in the manufacturing process. For example, a bleached kraft pulp mill can utilize 4,000-12,000 gallons of water per ton of pulp produced (USEPA 2002b). Diverting water from streams, rivers, and estuaries for pulp and paper mills can entrain and impinge eggs, larvae, and juveniles and may impact local populations of fish and invertebrates. Information is not available on the potential magnitude of entrainment and impingement impacts from wood, pulp, and paper mills. Refer to Physical Effects: Water Intake and Discharge Facilities for more information on entrainment and impingement impacts.

Thermal discharge

Pulp and paper production involves thermal and chemical processing to convert wood fibers to pulp or paper and may result in the release of effluent water with higher than ambient temperatures. There is a potential for cold-water fish such as Atlantic salmon and rainbow smelt to be adversely affected by these facilities. However, information is not available on the potential magnitude of thermal discharge impacts from wood, pulp, and paper mills.

Reduced dissolved oxygen

Pulp and paper mill wastewaters generally contain sulfur compounds with a high biological oxygen demand (BOD), suspended solids, and tannins (USEPA 2002b). The release of these contaminants in mill effluent can reduce dissolved oxygen in the receiving waters. According to the US EPA, however, all kraft pulp mills and nearly all US paper mills have chemical recovery systems in place and primary and secondary wastewater treatment systems installed to remove particulates and BOD (USEPA 2002b).

Conversion of benthic substrate

Sawdust and pulp from sawmills and lumber processing facilities can enter streams and rivers, adversely affecting benthic habitats for anadromous fish (Moring 2005). Pulp and paper mill effluent can contain solid particulates and a high BOD that can alter the benthic habitat of receiving water bodies. The impacts to benthic habitat from past practices of wood, pulp, and paper mills are evident today in some streams and rivers of Maine, including the Penobscot River from Winterport to Bucksport (USFWS and NMFS 1998). Most of the bottom substrate in this stretch of the Penobscot River is covered by bark and sawdust, which substantially reduces the diversity of benthic organisms (USFWS and NMFS 1998). However, chemical recovery systems and wastewater treatment systems should reduce or eliminate most solid wastes from the effluent stream.

Alteration of light regimes

Lumber, pulp, and paper mills releasing effluent containing solids, a high BOD, and tannins can reduce water clarity and alter the light regimes in receiving waters. This can adversely affect primary production and SAV in riverine and estuarine habitat where these facilities are located. Information is not available on the potential magnitude of light regime impacts from wood, pulp, and paper mills.

Conservation measures and best management practices for timber and paper mill processing activities

1. Ensure that lumber, pulp, and paper mills have adequate chemical recovery systems and wastewater treatment systems installed to reduce or eliminate most toxic chemicals and solid wastes from the effluent stream. Ensure that effluent streams do not elevate the ambient water temperatures of the receiving water bodies.
2. Discourage the construction of new lumber, pulp, and paper mills adjacent to riverine and estuarine waters that contain productive fisheries resources. New facilities should be sited so as to avoid the release of effluents in wetlands and open water habitats.
3. Use seasonal restrictions to avoid impacts to habitat during species' critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

4. Incorporate watershed analysis into new lumber, pulp, and paper mill facilities, with consideration for the cumulative effects of past, present, and future impacts within the watershed.

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