Part IV:

Effects of Grazing Animals, Birds, and Fish on Water Quality

Little green herons (Butorides virescens) are common to most water areas.
Photo by Bill Lea

Chapter 14

Domestic Grazing

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Introduction

Livestock grazing is a significant use of rangeland, and grazing practices can affect the quality of public drinking water sources. In general, activities that provide healthy range usually help maintain—or at least do not significantly degrade—water quantity and quality for domestic use. Rangeland management is not simply another phrase for livestock management. Rangeland often has climate, soils, topography, and precipitation characteristics or all that are unsuitable for intensive agriculture without irrigation or other intensive managerial inputs. Many rangelands have trees and are grazed.

Western rangelands are emphasized because most livestock grazing on natural forests and grasslands occurs in the West. Some also occurs in other regions. The publications cited here are meant to reflect physical and biological principles associated with water quality and livestock use. Therefore, while specific effects of livestock or water quality may vary, the underlying principles should be consistent.

Erosion and Sedimentation

Erosion and its consequence, sedimentation, are generally considered to be the number one problem associated with wildland watershed management.

Issues and Risks

Overgrazing weakens or kills vegetation, reducing soil cover and thereby accelerating surface erosion. With increased erosion, soil fertility declines and sediment yields increase. When significant amounts of sediment enter stream channels from rangeland, channels destabilize and widen, creating additional sources of sediment (U.S. Department of the Interior, Bureau of Land Management 1993, 1998). Sediment reduces water clarity and the oxygen-carrying capacity of the stream. Nutrients attached to sediment heighten the possibility of eutrophication. See chapter 2 for more discussion of sediment impacts on drinking water quality.

Findings from Studies

Considerable research is available on the relationships between livestock grazing and erosion and sedimentation (fig. 14.1). Several textbooks summarize the effects of livestock numbers, livestock types, timing of grazing, and animal distribution on vegetation and erosion (Holecheck and others 1989, Stoddart and others 1975). At high densities, grassland vegetation promotes production of soil organic material and increases infiltration rates (Buckhouse and Gaither 1982, Buckhouse and Mattison 1980). Therefore, grazing should be managed to maintain the density of vegetation, reducing erosion, and sediment yields.

In the riparian zone, the relationship of livestock grazing to streambank erosion has been studied (Bohn and Buckhouse 1985, Buckhouse and Bunch 1985, Buckhouse and others 1981). These researchers found it is possible to manage livestock grazing in ways that enhance riparian vegetation and protect streambanks. Grazing throughout the growing season harms vegetation and results in increased streambank sloughing. Conversely, grazing that is timed to accommodate plant growth and physiology can have positive effects on streams and the quality of water in them. In Oregon, for example, early-season grazing enhanced riparian shrub growth (Buckhouse and Elmore 1997).

J.M. Skovlin (1984) prepared an excellent review of livestock grazing research. He described effects on vegetation, streambank stability, and various aspects of water quality. He also compiled a large reference list and provided recommendations and prescriptions for grazing management. This document is an exhaustive look at many aspects of grazing management.

Reliability and Limitations of Findings

This work has been repeated and verified in several locations by several researchers. It is known that loss of plant

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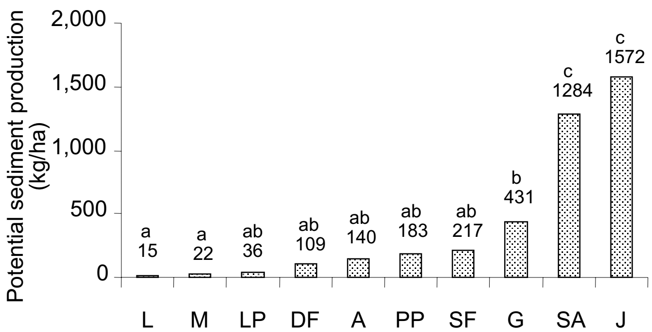

Figure 14.1—Potential sediment production in 10 Blue Mountain ecosystems in Oregon. Ecosystems: L = larch, M = meadow, LP = lodgepole pine, DF = douglas-fir, A = alpine, PP = ponderosa pine, SF = spruce-fir, G = grassland, SA = sagebrush, J = juniper (Buckhouse and Gaither 1982). Different lower-case letters indicate differences in statistical significance (P<0.10).

cover increases sediment yield. The key to applying findings is to think in terms of plant physiology and plant response to grazing. The goal of proper grazing is to maintain vegetation and soil organic material, preserving the soil's ability to infiltrate water, resist erosion, and store and slowly release precipitation.

Managerial success depends on understanding ecosystems, the vegetation present or desired, and management objectives, and then prescribing herbivory appropriate to the site. The Forest Service and the U.S. Department of the Interior, Bureau of Land Management, have cooperated to develop Proper Functioning Condition (PFC), a first-cut methodology to monitor wildland streams. Wayne Elmore and his riparian team have based their approaches on these concepts, which have been widely adopted (U.S. Department of the Interior, Bureau of Land Management 1998). However, there have been no systematic studies of how effective these methods are for protecting the quality of public drinking water sources.

Research Need

Refinement of the relationships among herbivory, vegetation, and sediment production on specific sites in specific ecosystems needs more research.

Bacteria and Protozoa

Waterborne, pathogenic bacteria and protozoa have long been recognized as causes of human disease. Many diseases can be transmitted only among members of the same species, but a significant number can be transmitted to hosts of different species. The concern is that contamination of the drinking water supplies by humans and by a variety of animal species poses hazards to human health.

Issues and Risks–Fecal Bacteria

Escherichia coli is a ubiquitous bacterium found in the gut of all warm-blooded animals. It is used as an indicator species in bacteriological testing. Other pathogenic organisms are difficult to trap, difficult to analyze, and expensive to process. As a consequence, testing for fecal coliform bacteria has become the accepted surrogate sampling protocol, with the understanding that if fecal coliforms are present, then pathogens are potentially present. *Escherichia coli* was long considered to be benign. However, in recent years several pathogenic strains of *E. coli* have developed and gained national attention due to the health risk they pose.

Findings from Studies (Bacteria)

Walter and Bottman (1967) reported on the two tributaries of the watershed supplying the city of Bozeman, MT, with its drinking water. One tributary was fenced and human activity was limited. A corresponding tributary was not restricted from human entry. The fenced watershed consistently had higher fecal bacteria loads than did the open watershed. After considerable monitoring and study, it was realized that the closed watershed had become a de facto refuge for wildlife. The increased animal use resulted in the higher fecal bacteria numbers in streamwater.

Coltharp and Darling (1973) studied three neighboring watersheds with different combinations of animals grazing and browsing: wildlife, sheep and wildlife, and cattle and wildlife. They found the lowest numbers of bacteria in the streams in the wildlife-only watershed. The sheep-and-wildlife watershed was next lowest, and the cattle-and-wildlife watershed had the highest bacteria counts. There was high statistical variation in the numbers, but in all three strategies, the bacterial counts were <100 per 100 milliliters (ml). The authors attributed the differences to animal numbers and distribution. The cattle tended to congregate near the stream, while the sheep were herded and spent more time in the uplands.

Bohn and Buckhouse (1981, 1983) sampled water in northeastern Oregon and found similar results. On watersheds with a resident deer and elk population, where grazing by livestock was excluded for several months during the winter, the bacteria numbers were low (10 to 20 per 100 ml). At the end of the summer, after livestock had grazed the area for several months, the bacteria numbers were slightly elevated (20 to 40 per 100 ml).

Research in central Oregon studied the fate of the coliform bacteria (Biskie and others 1988; Larsen and others 1988, 1994; Moore and others 1988; Sherer and others 1992). In this Great Basin rangeland, they discovered that statistically only 5 days per year experienced enough precipitation to produce overland flows. Consequently, the probability of washing fecal material into streams was relatively low. Cows defecated approximately 11 times a day, but less than one of these defecations landed in the stream directly or within 1 meter of the stream where it might be washed into the stream. Further experiments were conducted to determine the fate of bacteria defecated directly into the stream. Ninety percent of these bacteria precipitated to the stream bottom and attached to sediments. Sediment samples collected over the next several weeks showed that 90 percent of the lodged bacteria had died within 40 days (Biske and others 1988; Larsen and others 1988, 1994; Moore and others 1988; Sherer and others 1992).

The same team of researchers studied the effect of a strategically placed watering trough on livestock use of a flowing stream in both summer and winter (Clawson and others 1994, Miner and others 1992). When snow covered the ground, cattle were fed hay, and 95 percent of them used the ground water-fed trough, as opposed to 5 percent that used the stream. It is speculated that the warmer ground water (approximately 50 °F or 10 °C) held much greater appeal to the cattle than did the 32 °F (0 °C) creek. In the summer, riparian zones provided lush vegetation, shade, and water. The trough relieved some impact during the summer, but not as dramatically as during the winter. In late summer, when most of the available vegetation near the riparian zone had been consumed, approximately 25 percent of the livestock drank from the trough, while the remaining 75 percent preferred the stream.

Findings from Studies (Protozoa)

Giardia and *Cryptosporidium* have drawn considerable attention recently. Both are debilitating to humans and can be carried by a wide variety of warm-blooded animals from waterfowl to rodents; from deer, elk, and beaver to livestock (see appendix B and chapter 15). Both *Giardia* and *Cryptosporidium* have been known for decades, but only recently have routine testing following gastrointestinal complaints from citizens been conducted. It is probable that what is now diagnosed as *Cryptosporidium* would at an early time have been seen simply as flu or food poisoning.

Cryptosporidium oocysts have been found in association with both wild and domestic animals. Calves consistently shed greater numbers of oocysts than do older animals (Atwill 1996). Apparently by 4 months of age, calves develop a resistance and the number of oocysts shed is dramatically reduced. An alternative to livestock exclusion from areas where *Cryptosporidium* may be a concern is to ensure that livestock grazing the watershed are older than 4 months. The relationship between oocysts and age of wild animals is unknown and represents a research question.

Reliability and Limitations of Findings

The fecal bacteria research is reliable and has been consistent over time. The *Cryptosporidium* work, while compelling, is relatively recent.[2] Tate and his colleagues at the University of California, Davis, continue to investigate these relationships, the biology, and the management of *Cryptosporidium*. Conceptually, these experiments were solid. Site-specific relationships dictate specific biological responses. However, regional climatic and temperature differences may influence the range of variability inherent in these relationships and to date little is known about wild animals except that they carry the organisms and shed them in their feces. Water from wildlands including wilderness, can contain pathogens that cause human disease if the water is not adequately treated for purification.

Research Needs

Cryptosporidium research is still in its infancy. Further studies dealing with the origin and fate of the organisms are needed. Very little is known about pathogenic *E. coli* in livestock under range conditions, and further investigation is needed.

Chemical and Nutrient Impacts

A number of chemical compounds are associated with sediment transport. Rangelands are sometimes treated with herbicide or fertilizer compounds, but the primary chemical or nutrient problems are with phosphate (PO_4^{+3}) and nitrate (NO_3^{-1}) associated with eroding soils and fecal material.

Issues and Risks

Cycling of phosphate and nitrate are essential to plant growth. When vegetation is grazed, potential problems exist where phosphates and nitrates from feces or attached to

[2] Personal communication. 1999. Kenneth Tate, Professor, Department Agronomy and Range Science, University of California, Davis, CA 95616.

erosion particles that find their way to a stream. Excessive levels of these nutrients in streams can produce algal blooms and eutrophication. See chapter 2 for discussion of nutrient impacts on drinking water.

Findings from Studies

Frequently phosphate and nitrate reach streams in association with sediments. See chapter 3, which discusses overland flow, erosion, and sediment transfer.

When fecal material enters a stream, phosphate and nitrate concentrations rise, but wetlands can reduce these concentrations. On the Wood River system in Oregon, a nutrient loading was studied on streams originating from the Crater Lake National Park, traversing national forest, then private grazing land, and emptying into a lake listed as hypo-eutrophic. The concern had been that nutrient loading would be exacerbated when the water flowed through the grazed land due to fecal contamination. The data did not bear out this fear. In fact, the phosphate and nitrate levels decreased.[3] It was speculated that the wetlands in the system represented a natural nutrient sink. In wetlands, chemical processes associated with anaerobic conditions reduced phosphate and nitrate concentrations. Furthermore, wetland plants take up nutrients from the aqueous system. If animals eat wetland vegetation, nutrients are consumed. Thus, these nutrients are not redistributed back into the water as when the plant senesces in place and dies. Apparently the livestock grazing the wetland consumed the vegetation and its nutrients, and later redistributed the nutrients away from the stream in their feces. The result was the observed decline in water-borne nutrient concentrations.

Reliability and Limitations of Findings

The relationship between nutrient loading and sediment is clear. The relationship between livestock grazing of wetlands and the possibility of nutrient loading abatement is not proven. The relationships among erosion, sedimentation, and nutrient loading are universal and are bases for erosion control worldwide. The possibility of using livestock for biological control of weeds, for improving plant communities, for promoting species that encourage infiltration and reduce overland flow, and even for reducing nutrient loading (Bedell and Borman 1997) are based on solid research and management experience. These concepts are predicated on the ability of vegetation and organic material to enhance infiltration, which reduces overland flows and subsequent erosion. The concept of using livestock to harvest nutrient-rich wetland vegetation is logical but not tested.

Research Needs

Further research is needed on the relationships between livestock harvesting of streamside vegetation and nutrient loading of streams.

Key Points

In rangeland, grazing can affect drinking water. Water quality can be protected by nurturing upland and riparian vegetation, which can increase the soil's infiltration capacity and reduce surface runoff. By understanding the relationships between plant physiology and animal herbivory, one can tailor grazing practices to enhance infiltration. Both timing and intensity of grazing must be managed. Increased infiltration reduces sediment yield, bacterial counts, nutrient concentrations, and water temperatures. Published data clearly indicate that improper, abusive grazing can degrade the quality of public drinking water sources. It is also clear that proper, prescriptive grazing can produce positive environmental benefits, and research is needed to develop and test methods to accomplish them.

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Chapter 15

Wildlife

Arthur R. Tiedemann[1]

Introduction

Numbers of large herbivores—mainly deer and elk—are increasing throughout the United States (Riggs and others, in press) with a commensurate increase in potential for them to have an effect on the quality of drinking water sources. In general, activities that provide healthy habitat usually help maintain—or at least do not significantly degrade—water quantity and quality for domestic use. However, contamination of surface waters by wild herbivores and disease-organism transmission among domestic herbivores and wide-ranging large herbivores are major issues that must be addressed by land managers. Emphasis of this chapter is the role of large, wild herbivores, such as deer, elk, and moose on microbiological quality of wildland surface water. Information is also provided on the role of beavers and muskrats.

Issues and Risks

Presence of disease-causing organisms in wildland surface waters is the most critical aspect of problems related to the influence of wildlife on water quality. There is no doubt that the human pathogens *Giardia* spp. and *Cryptosporidium* spp. (appendix D), and pathogenic *Escherichia coli* (*E. coli*) are carried by and can be spread by a wide variety of wildlife.

The impact of large, wild herbivores, such as deer, elk, and moose, on water quality is an elusive and difficult problem. These animals range widely and unpredictably, and their densities and movements relative to surface waters are very difficult to quantify.

Presence and numbers of fecal coliform (FC) in a given volume of streamwater [usually number per 100 milliliters (ml)] are used as indicators of the potential for presence of disease organisms. At FC counts between 1 and 200 per 100 ml of water, the percentage occurrence of salmonella disease organisms is 28 percent (Geldreich 1970). Occurrence of salmonella increases to 85 percent for FC counts of 200 to 2,000 per 100 ml of streamwater and to 98 percent at FC levels in excess of 2,000 per 100 ml. Bohn and Buckhouse (1985) comprehensively reviewed the use of FC as an indicator of wildland water quality. Use of FC counts as an indicator of disease bacteria has several drawbacks. For example, it is not a satisfactory indicator for *Giardia.*

Fecal streptococcus (FS) counts are also used as indicators of the presence of disease organisms in water (Sinton and others 1993), but there are no established standards as there are with FC.

The ratio of FC to FS is one measure of the source of bacterial contamination of wildland surface water (Geldreich 1967). Geldreich (1976), Geldreich and Kenner (1969), and Van Donsel and Geldreich (1971) established ranges of FC to FS—in feces for humans, >4; cattle, 1.2 to 0.8; cattle and wildlife mixed, 0.08 to 0.04; and wildlife, <0.04. Tiedemann and Higgins (1989) and Tiedemann and others (1988) applied the concept to wildland watersheds where several watersheds received only wildlife use and others received varying degrees of cattle use and wildlife use. For watersheds with no cattle use, the FC to FS ratio was <0.04 for 90 percent of the samples collected. On watersheds with intensive cattle use of 7 acres [2.8 hectares (ha)] per animal unit month (aum), the FC to FS ratio in 75 percent of the samples was between 1.2 and 0.8. On watersheds with lower intensities of cattle use [19 to 20 acres (7.7 to 8.1 ha) per aum], the ratio suggested a mixture of cattle and wildlife use. Thus, the ratio established by Geldreich appears to have potential as a tool to separate wildlife and cattle sources of pollution. Baxter-Potter and Gilliland (1988) also concluded that the ratio was useful for distinguishing contaminant sources if the pollution had not aged in the stream.

Recent efforts have focused on determination of the presence and sources of actual disease organisms in surface water. Outbreaks of severe, bloody diarrhea associated with *E. coli* [O antigen 157 and H antigen 7 (O157:H7)] (Armstrong and others 1996) and numerous reports of *Giardia* infection (Moore and others 1993) have been

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responsible for emphasis on these organisms. Most cases of *E. coli* O157:H7 infection and death have been caused by consumption of infected meat (Armstrong and others 1996), including deer jerky (Keene and others 1997). However, multiple illnesses and deaths have occurred as a result of drinking contaminated municipal water (Swerdlow and others 1992). In the case of *E. coli*, until 1982, this organism had not been considered a disease-causing entity (Riley and others 1983, Wells and others 1983). As discussed previously, *E. coli* was formerly considered to be benign and an indicator organism for the presence of organisms that actually cause diseases.

Severe illness and deaths resulting from *E. coli* O157:H7 have prompted accelerated research to determine presence and quantities occurring in various animal species including wildlife. This is usually done by culture of samples of fresh fecal material (Atwill and others 1997, Goodrich and others 1973, Monzingo and Hibler 1987), entrail samples from harvested animals (Atwill and others 1997, Frost and others 1980), or samples from live animals (Erlandsen and others 1990). Transmission among domestic and wildlife species (especially those with wide ranges) is a crucial facet of this problem with far-reaching implications for drinking water quality. Large herbivores, such as deer, elk, and moose, are without boundaries and may serve as a vector for transmission of disease organisms among domestic livestock in pastures or on rangelands. This concern is reinforced by results of Sargeant and others (1999), who found similar genetic strains of *E. coli* O157:H7 in cattle and free-ranging white-tailed deer sharing the same pasture. Both types of animals serve as reservoirs for *E. coli* O157:H7. Although their conclusions were directed at consumption of deer meat, their results suggest that we should be alert to potential problems with the quality of surface drinking water sources.

Free-ranging white-tailed deer have also been shown to be potential sources of contamination of *Giardia* and *C. parvum* (Rickard and others 1999). These authors concluded "the abundance of water throughout the State (Mississippi) coupled with an overpopulation of white-tailed deer indicates this cervid may pose a threat to surface water of this area."

Relations among wild herbivores and water quality are highly complex involving the physical and vegetal nature of the landscape, characteristics of surface water, the species of wildlife, interrelations among wildlife and domestic animals, and the disease or indicator organism involved. Land management activities that tend to concentrate wildlife or result in increased densities also will influence water quality. Landscape characteristics that would tend to influence the effect of wild herbivores on water quality would be those that encourage or discourage high animal concentrations near surface water, such as extremely steep terrain or very dense vegetation. Stream characteristics that influence organism concentrations are discharge, turbidity, conductivity, pH, and temperature. Diurnal fluctuations of bacterial counts are related to discharge, but evidence is contradictory. Bohn and Buckhouse (1985) provide detailed analyses of watershed characteristics that influence FC numbers in streamwater. According to these authors, bacterial counts generally increase with increasing discharge. Increased counts are apparently the result of increased flushing of streambanks and associated fecal deposits. Sediment transport and associated organisms may also account for some of the increase in counts with increasing discharge. Counts of FC have been shown to be much higher in sediments than in surface water (Skinner and others 1984, Stephenson and Rychert 1982). Counts of FC seem to be inversely related to stream temperature (Geldreich and Kenner 1969). Extremes of pH also influence FC viability with 5.5 to 7.5 as an optimal range (McFeters and Stuart 1972). Type of wildlife species present is a major determinant of the type and number of disease organisms present in surface water. Wildlife closely associated with water, such as beavers and muskrats, may cause a protracted, relatively stable contamination problem that may be fairly predictable. Contamination by wider ranging wildlife, such as deer and elk, will likely be transient, sporadic, and somewhat unpredictable. Type of organism present also depends to some degree on the species of wildlife present. *Giardia*, for example, appears to be more closely tied to presence of water-associated wildlife, such as beavers and muskrats, than deer and elk (Monzingo and Hibler 1987). This does not exclude deer and elk as an element of the cycle of the organism or as a transmission mechanism. The disease-causing organism *E. coli* O157:H7 appears to be more closely related to ruminants than to animals with simple stomachs (Armstrong and others 1996).

Persistence of fecal organisms in surface water is an important consideration. In the case of domestic animals, FC levels in streamwater remain high for many months after cattle are removed (Jawson and others 1982, Tiedemann and others 1987). We don't know if the same is true for wildlife effects on water quality. Fecal coliform do survive for long periods—at least 1 year in feces of both domestic (Clemm 1977) and wild herbivores (Goodrich and others 1973).

Complexity also arises from the rigorous sample collection, transport, and analytical procedures that must be followed to obtain accurate results. Isolation of actual disease organisms is a complicated laboratory procedure that may also be very costly. Sampling schedules must be carefully adhered to.

Land treatment measures such as forest thinning, prescribed burning, shrub control, seeding, and fertilization have the potential to alter wild herbivore-use patterns. Some treatments, such as prescribed burning, are done to improve wildlife habitat. These treatments have direct effects on water quality that are discussed in chapters 10, 12, and 14 of this report. Because the treatments have the potential to also alter wild herbivore-use patterns, there is a potential for indirect effects on water quality. If these habitat modifications concentrate animals near streams and near domestic water supply withdrawals, water-quality impacts could be serious. However, information is lacking on effects of wild herbivores on water quality associated with changes in habitat and resultant alterations in herbivore-use patterns.

Findings from Studies

Very little research has been conducted on large, wild herbivores or beavers and muskrats as the identifiable sources of fecal contamination of wildland surface water. Results of studies of maximum levels of FC and *Giardia* resulting from wild herbivore use are portrayed in table 15.1. Walter and Bottman (1967) provide some of the earliest information on effects of wild herbivores on water quality. They studied FC counts in two watersheds that serve as a source of municipal water for Bozeman, MT. One watershed was used by recreationists; the other was fenced and patrolled to exclude the public and livestock. Thus, the only potential source of FC in the closed watershed was wildlife. Deer, elk, and moose were present in the closed watershed in undetermined numbers. They found maximum FC counts exceeding 200 per 100 ml of streamwater in the closed watershed. Fecal coliform counts were actually much higher in streamwater in the closed than in the open watershed, suggesting higher wildlife populations in the closed watershed—perhaps as a result of high levels of human use of the open watershed or watershed characteristics.

In another early study, Kunkle and Meiman (1967) measured maximum FC counts of 25 per 100 ml in streamwater from an area essentially free from human impact—very limited hiking or camping, and no domestic livestock grazing. Wildlife species were not listed, but it is safe to assume that the area is inhabited by mule deer.

Maximum FC (100+ per milliliter) and *Giardia* (1 per 100 ml) levels were also high in streamflow from a pristine, forested watershed in western Washington. These levels were presumably from wildlife contamination because human use was very light [5 to 30 days per year per 0.6 miles (1 kilometer) of stream]. Deer, elk, beavers, mountain beavers, river otters, and marmots were listed as possible sources of contamination.

Streamwater from pristine land in southern Finland was shown to contain high levels of FC (maximum, 268 per 100 ml of streamwater). The high counts apparently resulted from wild deer and moose use of the watershed (Niemi and Niemi 1991).

In eastern Oregon, forested watersheds that supported no domestic grazing had maximum FC counts in excess of 500 per 100 ml of streamwater (Tiedemann and others 1987). Deer and elk were the predominant large herbivores inhabiting the watersheds.

Maximum *Giardia* count observed by Monzingo and Hibler (1987) was 0.06 per 100 ml of streamwater in beaver ponds in Colorado.

Streamflow from watersheds without domestic livestock in Utah (Doty and Hookano 1974) and Wyoming (Skinner and others 1974) contained relatively high counts of FC—22 to 183 per 100 ml. Although FC origin was attributed to wildlife in both studies, there was no mention of which wildlife species were responsible. Recreational use in the two studies was limited to hiking.

Reliability and Limitation of Findings

Research to date lacks replication or detailed examination of species responsible, numbers of each species, and their distribution. Its results, however, indicate that wild herbivores pose a risk to drinking water quality.

Studies spanned a relatively broad geographical scope and suggest that drinking water quality may be a problem wherever there is contact between wild herbivores and surface water.

Changes in habitat, whether deliberate or uncontrolled, that attract wildlife to surface drinking water sources may increase the risk of introducing contaminants. Management that discourages animals from concentrating near streams that are sources of public drinking water may help alleviate potential contamination problems.

Table 15.1—Streamwater fecal coliform and *Giardia* responses to herbivore use

			Maximum counts observed[a]		
Location	Setting	Herbivore	Fecal coliform	*Giardia* spp.[b]	Reference
Colorado	Beaver ponds	Beaver	Not measured	0.021	Monzingo and Hibler 1987
Washington	Pristine forested watershed, low-level human use	Beaver, mountain beaver, otter, marmot	100+	1	Ongerth and others 1995
Southern Finland	Pristine lands	Elk, deer	268		Niemi and Niemi 1991
Eastern Oregon	Forested watersheds, no domestic livestock use	Deer, elk	500+		Tiedemann and others 1987
Montana	Municipal watershed, closed to public access	Deer, elk	200+		Walter and Bottman 1967
Colorado	Area essentially free of human impact, no domestic livestock use	Not indicated	25		Kunkle and Meiman 1967
Utah	Watersheds with no livestock use	Not indicated	36–183		Doty and Hookano 1974
Wyoming	Watershed open to hikers, no livestock use	Not indicated	22		Skinner and others 1974

[a] Counts per 100 milliliters of streamwater.
[b] Locations with no data in this column indicate that they were not measured.

Research Needs

1. Carefully controlled experiments are needed to determine the magnitude of the effect of wild herbivores on microbiological water quality. Such research must separate effects of domestic herbivores and humans from those that result from wildlife. Research must also document the species of herbivore, the amount of time that each spends near surface water, and organisms associated with fecal deposits. Carefully designed water sampling procedures must accompany these studies. Samples above, within, and below areas of activity of sufficient frequency to represent all hydrograph stages will be essential.
2. Landscape-scale satellite animal tracking experiments with large, wild herbivores, such as the Starkey Experimental Forest and Range studies in northeast Oregon (U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, La Grande, OR), provide opportunities to relate large herbivore movements by species to changes in water quality. Rationale and methodology of those studies could be used as a model for design of water-quality studies. Starkey's studies (Rowland and others 1997) could also serve as a model for research to determine relations among forest and rangeland treatments, wild herbivore-use patterns, and resultant changes in water quality.

3. Perhaps it would be appropriate to explore advanced technology to discourage large, wild herbivores, such as the technique described by Tiedemann and others (1999) for cattle. This technique would probably be appropriate primarily where wild herbivore contamination of surface water creates severe risks from drinking the water.

4. The literature shows that microbiological and epidemiological research on *Giardia* and *E. coli* O157:H7 is well underway. Hancock and others (1998), however, pose some problems that are urgently in need of resolution; *E. coli* O157:H7 may: (1) have multiple species in which it resides for long periods; (2) be capable of transiently colonizing many species; and (3) have an environmental source, such as sediments where it may be able to multiply prolifically. Similar questions should be raised with regard to *Giardia*.

Key Points

1. Presence of wild herbivores has the potential to influence microbiological quality of wildland surface water and to render it unsafe for drinking unless it is adequately purified. It is important for wildland managers to understand the potential for a problem to exist even though they cannot document the actual source of contamination.

2. Relationships between wild herbivores and water quality are highly complex involving physical and vegetal landscape characteristics, hydrologic parameters (discharge, pH, temperature), type of contaminating organisms, species and numbers of animals, use patterns of animals, mixing of domestic and wild herbivores, length of time since animals were present, and land treatment measures that have been implemented.

3. Potential for presence of disease organisms such as pathogenic *E. coli* O157:H7 and *Giardia* emphasizes the urgency to understand the relations between wild herbivores and water quality. No studies have related water quality to wild herbivore species, numbers, and land-use patterns.

4. Land treatment measures such as thinning, prescribed burning, seeding, and fertilization, whether designed specifically for wildlife habitat alteration or other management purposes may alter herbivore-use patterns and exert secondary effects on water quality. These effects are presently undocumented and poorly understood.

5. Free-ranging large, wild herbivores may be vectors for transmission of disease organisms among domestic livestock. Associated contamination of surface water and potential public health hazards create an urgency to understand these relations and effects on water quality.

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Chapter 16

Water Birds

Christopher A. Nadareski[1]

Introduction

This chapter synthesizes the available information on the sources, mechanisms, and risks of drinking water contamination from water birds. By water birds, we mean geese, ducks, and other duck-like swimming birds such as cormorants, gulls, and wading birds. In general, activities that provide healthy habitat usually help maintain—or at least do not significantly degrade—water quantity and quality for domestic use. However, water birds have been implicated in the contamination of both large and small drinking water supplies.

Issues and Risks

The U.S. Department of Agriculture, Wildlife Services, collect and disseminate information about nuisance-related problems caused by a variety of birds. Birds commonly create human health concerns by polluting potable drinking water supplies and fouling recreation areas, such as swimming beaches. Species like the cormorant are thought to negatively impact recreational fisheries and drinking water supplies. Some terrestrial bird species, such as swallows, pigeons, and starlings, may nest, feed, or roost in water intake structures where their defecation has negative impacts on water quality. Biological, chemical, and nutrient pollutants may be released or deposited by water birds. The type and quantity of pollutant will determine what kind and level of water bird management is required to prevent contamination to a reservoir system.

Estimating impacts from the various types of contamination requires information on the species of water bird inhabiting the water supply, the number of birds per species, the daily defecation or pellet regurgitation rates, the amount of contamination per specified weight of feces or pellet, and the daily amount of activity by each bird on the water. The principal pathogens of concern are listed in table 16.1.

Findings from Studies

Studies have found that water birds and some terrestrial species affect the biological, nutrient, and chemical quality of water.

Contamination

Biological

Among the various types of water bird contaminants are excrement containing bacteria, protozoans, or enteric viruses. These contaminants are routinely monitored by water suppliers and regulated by the U.S. Environmental Protection Agency (EPA) and various State health departments. Numerous studies have documented the occurrence of fecal coliform bacteria and other pathogens in many North American water bird species (Ashendorf and others 1997, Gould and Fletcher 1978, Hatch 1996, Hussong and others 1979). As a result, bird control programs have been developed and implemented at many municipal water sources (Ashendorf and others 1997, Blokpoel and Tessier 1984). Water bird excrement has been reported to contain both human and nonhuman pathogens. Microbiological analysis for human bacterial pathogens found in drinking water are generally represented by the fecal coliform bacteria group which is used as an index to identify the probability one or more of these organisms will be present in the sample (chapter 2 and table 16.1). Fecal coliform originates solely from warm-blooded animals, and analytical methods to identify the origin of bacterial type (human versus nonhuman) are currently under investigation. These new methods require an expensive and time-consuming examination of the sample. As a result, most public water suppliers, at best, can only speculate on the origin of the drinking water bacterial contamination. In the larger municipal water systems, such as New York City's, methods are being developed to link bacterial sources from water samples to human, nonhuman, or both sources.

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Table 16.1—Indicator and principal pathogens of concern in contaminated drinking water

Organism type	Disease	Symptoms
Fecal coliform bacteria group		
Bacteria		
Escherichia coli, Klebsiella pneumonae	Diarrhea, dysentery, hemorrhagic colitis	Diarrhea, nausea, cramps, fever, vomiting, mucus in stools
Important human pathogenic organisms suspected from feces		
Bacteria		
Shigella spp.	Shigellosis	Diarrhea, fever, cramps, tenesmus, blood in stools
Salmonella typhimurium	Salmonellosis	Abdominal pain, diarrhea, nausea, vomiting, fever
S. typhi	Typhoid fever	Abdominal pain, fever, chills, diarrhea or constipation, intestinal hemorrhage
Enterotoxigenic	Diarrhea	Diarrhea, fever, vomiting
Campylobacter jejuni	Gastroenteritis	Abdominal pain suggesting acute appendicitis, fever, headache, malaise, diarrhea, vomiting
Vibrio cholerae (incidence rare or negligible in the United States)	Gastroenteritis	Vomiting, diarrhea, dehydration
Yersinia spp.	Plague, hemorrhagic enterocolitis, terminal ileitis, mesenteric lymphadenitis, septicemia	Diarrhea, fever, abdominal pain
Enteric viruses		
Hepatitis A virus	Hepatitis	Fever, malaise, anorexia, jaundice
Norwalk-like agent	Gastroenteritis	Diarrhea, abdominal cramps, headache, fever, vomiting
Virus-like 27 nm particles	Gastroenteritis	Vomiting, diarrhea, fever
Rotavirus	Gastroenteritis	Vomiting followed by diarrhea for 3 to 8 days
Protozoa		
Giardia lamblia	Giardiasis	Chronic diarrhea, abdominal cramps, flatulence, malodorous stools, fatigue, weight loss
Cryptosporidium	Cryptosporidiosis	Abdominal pain, anorexia, watery diarrhea, weight loss; immuno-compromised individuals may develop chronic diarrhea
Entamoeba histolytica	Amebiasis	Vary from mild diarrhea with blood and mucus to acute or fulminating dysentery with fever and chills

nm particles = nanometers.
Source: Murray and others 1995, Hurst and others 1997.

Nutrients

Contributions of nutrients to aquatic ecosystems by water bird excrement have been well documented (Gould and Fletcher 1978, Manny 1994), but debate continues over the significance of impacts from bird defecation on nutrient loading (Hoyer and Canfield 1994, Murphy 1984). Among the various nutrients identified in water bird excrement, nitrogen and phosphorus are of greatest interest. Both have the potential to increase the rate of eutrophication and degrade the quality of a drinking water supply (Vollenweider and Kerekes 1980).

Chemical

Another type of water bird contamination may be of chemical origin. Glandular releases, body oils, pesticides, and other hydrocarbons are transported by the birds. The impact to drinking water supplies from glandular releases and body oils emitted by water birds is not well understood. Chemical pollutants carried externally on feathers or vectored by water birds, although not well documented, may potentially cause contamination of a water supply. For example, many reservoir systems do not provide adequate food supplies for gulls or other opportunistic feeders. Gulls, therefore, will seek alternative foraging locations, such as agricultural areas, urban centers, moist fields, and landfills, where they may be exposed to a variety of chemicals either through ingestion or external attachment. The gulls may accumulate various chemicals on their feathers and transport them back to the reservoir where they roost. Gulls may also ingest contaminated materials from landfills or sewage treatment facilities, carry them back to the reservoir, and regurgitate them. Additional studies are needed to determine these impacts.

Water Birds as Vectors of Contamination

A variety of human-related activities, such as urbanization, resource exploitation, agriculture, and land conservation, have the potential to promote or discourage populations of a variety of water bird species.

Water birds deposit pollutants in drinking water supplies during roosting, foraging, and overflights. The birds may acquire pathogens, such as *Giardia* spp. or *Cryptosporidium* spp., from domestic farm animals (Graczyk and others 1998) and from urban centers such as shopping malls or landfills. Agricultural operations, such as the spreading of fodder or manure, growing crops, and tilling soil, offer attractive foraging locations for some species that travel great distances. In a study of Canada geese foraging on agricultural land near the Chesapeake Bay, researchers identified a high incidence of *Giardia* and *Cryptosporidium* in their fecal matter (Graczyk 1996) compared to an extremely low incidence of the same two protozoans in geese sampled at an urban reservoir 15 miles north of New York City.

The pathways by which water contaminated with biological materials, chemicals, and nutrients can enter into the reservoir from water birds include streamflow through drainage basins, stormwater surface sheet flow, fly-over fecal releases, and direct fecal deposition. The location of the source of contamination with respect to a reservoir will determine the degree of water-quality impacts. Size and water flow patterns in relation to the water intake structure from which drinking water is drawn also affects the extent of impacts. The extent of contamination depends on the die-off rate, settling rate, and water travel time.

Seasonality of Impacts

Pollutant loadings from water birds vary widely by season. Migratory birds may cause problems only during brief stopovers. Local breeding populations of water birds may also have negative impacts, and those impacts may persist through much of the year. The location of bird activity (roosting, breeding, foraging, etc.) on the reservoir relative to a water intake facility may also determine importance of strategies for managing water bird populations.

Reliability and Limitations of Findings

The types of water-quality impacts are understood. The magnitudes of impacts are less well understood. Resident and migratory water birds will pose similar problems to water supply reservoirs. The magnitude of the impact will vary by species and number of birds inhabiting the reservoir, the surrounding environs and associated sources of contamination, and seasonal patterns of migration. Therefore, water bird impacts will vary and need to be assessed for each reservoir.

Key Points

1. Land managers may have different objectives concerning habitat management for water bird species than reservoir managers. Both forest managers and reservoir managers can and do influence the population dynamics of water bird species. Their management objectives can conflict; for example, the forest manager may want to increase populations of certain water bird species while the reservoir manager may try to decrease or eliminate their activity on or near the reservoir (see New York City case study).
2. To address the contamination of drinking water supplies by water birds, a comprehensive watershed protection plan should be drawn up. This plan needs to identify all major sources of pollution. If it is determined that water birds are major contributors, an additional plan for water bird management should be developed. This water bird management plan should also incorporate objectives both for the land manager and the reservoir manager. Populations of all water bird species that breed or migrate throughout the watershed should be inventoried to identify all potential impacts on water quality. The type of pollution should be identified, as should its potential origins. Where the source of the contaminant is human activity and birds are only a vector, it may be possible to control the contamination by changing the offending human activity.

Case Study: New York City Waterfowl Management Program

As the Nation's largest, unfiltered water supplier, the city of New York Department of Environmental Protection (DEP) is responsible for the maintenance of 19 reservoirs, 3 controlled lakes encompassing an area of almost 2,000 square miles, and serving 9 million consumers. Beginning in the early 1980's, the city enhanced its water-quality monitoring programs to address watershed protection issues. As more stringent Federal regulations were implemented through the Safe Drinking Water Act of 1986 and subsequent Surface Water Treatment Rule of 1989, New York City remained determined to maintain its unfiltered status through stringent criteria set by the EPA. In order to fulfill this filtration avoidance determination, the DEP developed a comprehensive Watershed Protection Program (WPP) to identify and eliminate sources of pollution that would compromise its water quality. An important component of the WPP was the implementation of a Waterfowl Management Program that identified birds, particularly gulls, geese, ducks, and cormorants, as the primary source of fecal coliform bacteria to the water system. Baseline bird population data was well correlated with the seasonal elevations of bacteria. As a result, DEP instituted a bird deterrent/harassment program to eliminate the presence of both breeding and migratory Canada geese and migratory gulls, ducks, and other water birds. Techniques used to deter the birds included shoreline fencing, meadow management to deter feeding opportunities, bird distress tapes, and the use of pyrotechnics from motorboats and hovercraft from dawn to dusk on a daily basis. The techniques were highly effective: elimination of defecation from roosting birds eliminated the seasonal elevations of bacteria, allowing New York City to maintain its filtration avoidance status.

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Chapter 17

Fish and Aquatic Organisms

C. Andrew Dolloff [1]

Introduction

Freshwater fish management can impact water quality by manipulating fish and other organisms and by altering the physical, chemical, or biological attributes of habitat. Fishery managers manipulate populations for a variety of reasons, including attempts to maximize yield, control size and age structure, establish populations of desirable and remove populations of undesirable species, and to reestablish populations and communities that have been extirpated. Habitat management often accompanies attempts to manipulate populations. All components of habitat are subject to manipulation, including not only the obvious structural elements, such as substrate, cover, and flow obstructions, but also water chemistry and the content of the biological community.

Fish Hatcheries and Aquaculture Facilities

Issues and Risks

Fish hatcheries or fish culture facilities can reduce water quality. Untreated effluent from these facilities typically consists of metabolic waste products and solids derived from uneaten fish food and fish wastes (Goldburg and Triplett 1997). In addition, culture facilities also may intermittently discharge pathogenic bacteria and parasites and the chemicals and drugs used in the prevention or treatment of disease (Liao 1970, Piper and others 1986). The usual waste stream from a culture facility can be treated as a chronic point source and effluent quality and quantity can be monitored at or immediately below the outfall. Monitoring results tend to be highly variable because of variation in production schedules and other activities (Foy and Rosell 1991) such as periodic cleaning and flushing (Bergheim and others 1984).

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Findings from Studies

The quality of effluent water varies considerably depending on the specific features of the culture system including the species of fish, intensity of production, the diet and feeding regime, and the temperature and chemical character of source water (Axler and others 1997). The four most important dissolved constituents of fish cultural wastewater include ammonia, nitrate, phosphate, and organic matter. Ammonia is toxic to most aquatic life and all four constituents are primary agents of eutrophication. Along with dissolved organic matter, suspended solids, which are predominantly organic, contribute to biological oxygen demand in receiving waters. Nutrient loading can be significant, as 60 to 75 percent of the nitrogen and phosphorus in fish food ultimately becomes part of the waste stream (Axler and others 1997). Unless intakes for domestic water supplies are located immediately downstream from the outfall, however, hatchery effluents are not likely to severely degrade domestic water supplies.

Effluents from trout farms may diminish water quality slightly during periods of low flow and high temperature (Selong and Helfrich 1998). In a study of five Virginia trout farms, Selong and Helfrich (1998) found that total ammonia nitrogen, un-ionized ammonia nitrogen, and nitrite nitrogen levels increased downstream from effluent outfalls but did not exceed thresholds for lethal exposure for aquatic organisms. Dissolved oxygen levels also decreased but were typically above 7.0 parts per million (ppm). Temperature, pH, nitrate nitrogen, and total phosphorus levels did not differ from upstream levels. Substrate embeddedness was greater below outfalls from two farms but settleable solids concentrations were always <0.1 ppm. The lack of significant water-quality degradation reflected the tendency of growers to adjust production to correspond to periods of high flow and low-to-moderate temperature (Selong and Helfrich 1998). In Washington State, however, hatchery effluents during the summer had significantly elevated temperature, pH, suspended solids, ammonia, organic nitrogen, total phosphorus, and biological oxygen demand (Kendra 1991). Phosphorus loading in hatchery effluent in one Washington State creek was equivalent to secondarily treated sewage discharge from a town of 2,300 people. The influence of hatchery effluents tends to be localized in the immediate downstream reach (Doughty and McPhail 1995). Effects on periphyton and macroinvertebrates were not detected about 1,200 feet [366 meters (m)] downstream of the outfalls from five Virginia trout farms (Selong and Helfrich 1998).

Because most of the total nutrient load produced at a typical facility is in the form of settleable solids, treatment usually consists of diverting wastewater through settling basins before discharge (Piper and others 1986). Much of the variation observed in effluent waste among facilities can be traced to differences in settling characteristics (Mudrak 1981). When located near towns or cities, culture facilities can avoid discharging directly into streams or rivers by connecting to municipal sewage treatment facilities.

Fish disease organisms, chemicals, and other additives commonly used in culture facilities also may influence the quality of water for domestic use. Fish trematodes, cestodes, and nematodes can be transmitted to people who eat certain species of raw fish. In general, however, fish diseases do not present risks to human health (Hoffman 1999). Most potential problems with fish disease and water quality arise from the chemicals and procedures used in treatment. At present, relatively few chemicals have been approved by the U.S. Food and Drug Administration (FDA) for use in the treatment of fish diseases. The antibacterials approved for use on food fishes include oxytetracycline, sulfamethoxine (Romet), and sulfamerazine. Most drugs are administered through feed, from which a considerable fraction may be released into the environment. Release occurs through three routes: uningested food, feces, and in urine and bile fluid (Capone and others 1996). Residues of oxytetracycline in sediments under net pens of intensively cultured (and treated) Atlantic salmon were present for at least 10 months after treatment (Capone and others 1996). Other drugs approved for use in treating fish include formalin (for the treatment of external parasites and fungus on fish eggs) and tricaine methanesulfonate, an anesthetic. The FDA also maintains a list of unapproved new animal drugs (drugs that have not gone through the formal approval process but are not expected to have a negative impact on the environment) for use in aquaculture of food fishes provided the following conditions are met:

1. The drugs are used for the prescribed indications, including species and life stage;
2. The drugs are used at the prescribed dosages;
3. The drugs are used according to good management practices;
4. The product is of an appropriate grade for use in food animals; and
5. An adverse effect on the environment is unlikely.

Among a host of common compounds and substances in this classification are sodium chloride and ice. Examples of unapproved drugs for use in aquaculture are acetic acid (parasiticide for fish), calcium chloride (ensures proper egg hardening, aids in maintaining osmotic balance in fish), carbon dioxide gas (fish anesthetic), hydrogen peroxide (fungicide), magnesium sulfate (controls monogenetic trematode and external crustacean infestations), potassium chloride (relieves osmoregulatory stress and prevents shock), povidone iodine compounds (fish egg disinfectant), sodium sulfate (improves egg hatchability), and urea and tannic acid (denatures adhesive component of fish eggs).

In addition to treating specific diseases, all culture facilities must undergo periodic cleaning and sterilization. Chlorine (HTH) is often used for this purpose; exposure to 5 ppm for 1 hour kills nearly everything. Chlorine rapidly loses its toxicity (1 day or less) and can be neutralized by sodium thiosulfate.

Reliability and Limitations of Findings

A large body of research has accumulated on the design, construction, operation, and maintenance of fish culture facilities. Because a significant portion of this research has addressed the issue of effluent management, the findings are considered highly reliable. These findings are widely applicable to flowing water.

Research Needs

None identified.

Key Points

Existing knowledge will permit managers and policymakers to make informed decisions about the impact of culture facilities on domestic water supplies.

Chemical Reclamation

Issues and Risks

Piscicidal (fish-killing) compounds have been used to sample, control, or eradicate fish populations since the 1930's (Bettoli and Maceina 1996). Purposes have included eradication of exotic species such as common carp from ponds, lakes, and reservoirs and removal of nonnative species from headwater streams. With the exception of sampling programs, the objective of most piscicide applications is to remove one or more species so that the water body can be stocked soon after poisoning with species considered more desirable.

Findings from Studies

Only registered piscicides may be applied to water in North America. Among a variety of possible compounds, only rotenone (trade name Noxfish), antimycin A (trade name Fintrol), 3-trifluoromethyl-4-nitrophenol (TFM), and Bayluscide (a nitosalicylanilide salt, trade name Bayer 73) are approved for use in the United States. Bayluscide and TFM, either alone or in combination, are used exclusively to sample or control sea lamprey, primarily in streams flowing into the Great Lakes (Bettoli and Maceina 1996, Marking 1992). In the United States, lampricides can be applied only by personnel certified by the U.S. Fish and Wildlife Service or an approved State conservation agency (Bettoli and Maceina 1996).

Rotenone, a naturally occurring chemical derived from the roots of tropical plants in the genera *Derris* and *Lonchocarpus*, has been used for centuries by native people to kill fish for food. Rotenone is highly toxic to fish, which are killed by disruptions in cellular respiration (Haley 1978). Most nontarget aquatic organisms usually are not affected by the concentrations of rotenone used to kill fish, but high doses can kill amphibians, some reptile species, and a variety of macroinvertebrates (Bettoli and Maceina 1996). The toxicity and persistence of rotenone are influenced by turbidity, temperature, and pH; in general, rotenone is most toxic in clear, warm, acidic water. Residues of rotenone were detectable in the bottom sediments of experimental ponds in Wisconsin for nearly 14 days during the spring at 46 °F (8 °C), but decreased below the limits of detection within 3 days during the summer at 72 °F (22 °C) and during the fall at 59 °F (15 °C) (Dawson and others 1991). Higher temperatures coupled with the presence of clay (bentonite) led to adsorption and rapid decline in residues. Dawson and others (1991) suggested that at warmer temperatures, water treated with rotenone would be safe for swimming immediately after treatment with a concentration of 250 parts per billion (ppb). A strong oxidizing agent such as potassium permanganate (applied at 2.0 to 2.5 ppm) will detoxify rotenone when applied downstream of treatment sections in flowing water or in lakes where managers wish to limit the area of kill.

Rotenone has a low mammalian toxicity (Marking 1988) and relatively short half-life (<1 day in water at 73 °F) (Gilderhus and others 1988). Nevertheless, negative public perceptions about the use of any poisonous substance in open water have curtailed the use of rotenone over the last decade. Older formulations of rotenone, no longer approved for sale in the United States, sometimes contained carrier substances such as trichloroethylene and piperonyl butoxide, which are known carcinogens. Residues of the latter were detected up to 9 months after treatment of Lake Davis in California and caused disruption of a public drinking water supply that drew national publicity.

Similar to rotenone, antimycin is relatively nontoxic to mammals (Herr and others 1967) but highly poisonous to fish. Antimycin toxicity in water varies by species, and concentrations over 100 ppb may be required to kill resistant species (Bettoli and Maceina 1996). The effectiveness of antimycin may decrease below 50 °F (10 °C) (Tiffan and Bergersen 1996), but in warm water, temperature does not greatly influence its toxicity. High turbidity (Gilderhus 1982) and alkalinity (Tiffan and Bergersen 1996) decrease its effectiveness and persistence (Bettoli and Maceina 1996, Lee and others 1971). Turbulence leading to oxidation and foaming also may contribute to antimycin inactivation (Tiffan and Bergersen 1996).

Reliability and Limitations of Findings

A large body of research has accumulated on the short- and long-term effects of chemical reclamation. Studies have been conducted in both warmwater and coldwater habitats under widely varying conditions. The findings are considered highly reliable and widely applicable.

Research Needs

None identified.

Key Points

Existing knowledge will permit managers and policymakers to estimate impacts of piscicides on fish populations and water quality. However, controversy likely will continue over the use of piscicides in sources of public water supplies.

Restoration and Reintroduction of Populations and Communities

Issues and Risks

With the growth in environmental awareness in recent years, management agencies increasingly are called upon to restore species that have been intentionally or accidentally extirpated from aquatic ecosystems. In most situations, the impact of the restoration on water quality will be almost entirely positive because improved water quality is one of the prerequisites for survival of target organisms. Managers must be aware, however, that one of the most obvious signs of a successful restoration—large numbers of fish—may contribute to periodic, temporary declines in water quality. Large numbers of fish may cause problems with water quality during periods of low flow and high temperature if the fish become stressed, die, and decompose. Large numbers of fish of a single species seldom die in a small area under such conditions except when anadromous fish such as Pacific salmon or alosids (shads and alewifes) congregate for spawning.

Findings from Studies

Although some aspects of water quality may be temporarily degraded by the decay of anadromous fish carcasses, the long-term effect can have great ecological value. Nutrients from anadromous fish carcasses help maintain the productive capacity of streams and riparian zones in coastal watersheds of the Pacific Northwest and Alaska (Cederholm and others 1989, 1999; Wilson and Halupka 1995) and streams of the Atlantic Coastal Plain (Garman and Macko 1998). On the west coast, the carcasses of abundant pink (Brickell and Goering 1970) and sockeye salmon (Kline and others 1994) and the less abundant coho salmon (Bilby and others 1996) contribute important nutrients, particularly nitrogen, to otherwise nutrient-poor watersheds. Similar relationships have been observed in Atlantic slope drainages (Durbin and others 1979, Garman 1992).

Accidental introductions generally are of greater concern both ecologically and for water quality. Perhaps the most troublesome, accidentally introduced aquatic pest is the zebra mussel *Dreissena polymorpha*. This bivalve mollusk first arrived in North America in ship's ballast via the St. Lawrence Seaway sometime around 1986 (Hebert and others 1989). Since that time, it has invaded all of the Great Lakes and the major rivers of the Eastern United States (Ludyanskiy and others 1993). Invasion of virtually all the major river systems in North America is viewed by some as inevitable, with only the specific timetable subject to question (Morton 1997). Zebra mussels will attach to virtually any surface, including the interior of water inlet pipes. Zebra mussels also will attach to the hulls of both large, commercial and smaller recreational vessels, which act as dispersal agents (Keevin and others 1992). The primary economic cost of the zebra mussel invasion has been the fouling of intakes for raw industrial and potable water. Zebra mussels may be present in numbers sufficient to clog water intakes, necessitating either abandonment or laborious and repeated cleaning of the pipes. Over $4 billion per year may ultimately be spent on attempts to control or mitigate zebra mussel impacts (Morton 1997). The ecological impacts of the invasion have been equally profound, particularly on native unionid mussels (Haag and others 1993). Nalepa and Schloesser (1993) completely reviewed issues surrounding the zebra mussel invasion.

The accidental introduction of the zebra mussel, while certainly regrettable, may have future benefits. Morton (1997) noted that in Europe, where the species has been established for around 170 years, zebra mussels are used as biomonitors for trace metals and radionuclides. Their natural water filtering abilities have made them useful both for restoration of natural water systems and in the treatment of human sewage. With development of genetically sterile stocks, it may be possible to employ zebra mussels or other suitable species in the cleanup of both natural and artificial water bodies in North America (Morton 1997).

Reliability and Limitations of Findings

Although this area of research and restoration is relatively recent, the findings are generally considered reliable. Restoration ecology is one of the newest branches of ecology. Relatively little research has accumulated and there are few long-term studies of the effects of reintroduced or accidentally introduced species. The likely impacts of exotic invasive species, such as the zebra mussel, on domestic water supplies, however, can be predicted with a high degree of precision.

Research Needs

1. Long-term studies are needed on the impacts of both reintroduced species and exotic species on habitat and water quality.
2. Additional research should address the losses of other species and reductions in water quality after introduction of exotic or previously extirpated species.

Key Points

The current body of research will permit managers to address some issues, but the long-term influence on water quality of repeated measures to control exotic species is unknown.

Physical Habitat

Issues and Risks

The literature on stream habitat improvement is large and diverse, ranging from simple handbooks and pamphlets designed for volunteers to more detailed treatments for biologists and other professionals, e.g., Hunter (1991). Most habitat improvements are designed to slow or redirect water flow or to create pools. Habitat improvements include engineered structures, such as k-dams, wing dams, and deflectors. Unless they are constructed with chemically preserved materials (such as creosote or pressure-treated wood), the materials used in most structures should not pose a direct threat to water quality. Indirectly, structures may cause changes in sediment storage and routing patterns by causing excessive scouring of channel bottoms and sides. Turbidity may increase after installation of even properly sited structures, but structures installed without regard for natural channel processes can cause major disruptions in flow patterns and trigger accelerated channel erosion.

Only recently have managers attempted to mimic the natural structure of streams by adding native materials such as large or coarse woody debris (CWD) to streams. For purposes of scientific discussion, CWD includes any piece of wood that is at least 4 inches [10 centimeters (cm)] in diameter and 3 to 4 feet (0.9 to 1.2 m) long (Bisson and others 1987, Dolloff 1994, Harmon and others 1986, Maser and Sedell 1994). In practice or application, managers typically consider CWD to be wood that is at least 12 inches (31 cm) in diameter with length equal to the width of the receiving stream channel. Logging residue or slash is excluded from most habitat enhancement projects because it tends to be unstable in all but the smallest stream channels. Woody debris enters stream channels naturally by a number of routes, including bank undercutting, windthrow, and as a result of catastrophic events, such as snow and debris avalanches and hurricanes. Managers add CWD by direct felling or toppling of streamside trees or by transport from more distant sources.

Findings from Studies

In general, the relatively small amounts of wood added by managers to enhance or restore stream habitat are not likely to exert a major impact on water quality. There can be exceptions when pieces dislodged during floods plug culverts, bridge openings, or other structures and cause accelerated erosion or the failure of streamside roads or road crossings. When large amounts of fine debris from bark and branches accumulate, dissolved oxygen may be depleted and hydrogen sulfide and ammonia produced (Sedell and others 1991). Leachates from logs may contain toxins, but they are unlikely to reach significant concentrations under natural conditions (Schaumburg 1973, Thut and Schmeige 1991).

Reliability and Limitations of Findings

Since intensive research began about 20 years ago, a large body of information has accumulated on the ecology and management of CWD in streams. Many studies, including historical observations and experiments, have been conducted in watersheds across North America and several other continents. Reliability is high.

Studies have demonstrated the benefits of large wood in streams. Whether in small streams or larger rivers, research suggests that wood in the water is good for fish and, except in certain well-defined situations, not detrimental to domestic water supplies.

Research Need

Research is needed to evaluate the influence of woody vegetation planted to stabilize fish habitat. For example, use of black locust or other nitrogen-fixing plants may increase nitrogen content of the water, resulting in either excessive algal blooms or the need to remove the nitrogen prior to domestic use.

Key Point

The information available should allow managers to address most issues related to the effects on drinking water of woody materials installed to improve fish habitat.

Liming of Acidified Waters

Issues and Risks

Water from areas where the bedrock does not have a high buffering capacity can be acidified by major soil disturbing activities such as road building, mining (Nelson and others 1991), or acid precipitation. Associated problems include disruption of physiological processes for many aquatic organisms and increased concentrations of toxic forms of metals such as aluminum. Left uncorrected, continuing acidification can kill entire faunas (Olem 1991). The quality of surface water can be dramatically improved by treating streams, lakes, or whole catchments with a soluble basic mineral such as crushed limestone.

Findings from Studies

The beneficial effects of liming have been known for hundreds of years (Henrikson and Brodin 1995, Porcella and others 1995). Liming, however, is at best a temporary solution and must be repeated to maintain water quality. The primary benefit of liming has been to preserve or recover fish stocks and diversity of aquatic species. Liming generally increases pH and reduces concentrations of metals, including toxic forms of aluminum (Wilander and others 1995). Concentrations of many other trace metals also decreases as pH increases (Vesely 1992). Liming may cause the precipitation of metals and stress to aquatic species present in mixing zones, such as in downstream reaches where acidic tributaries join with limed water (Henrikson and Brodin 1995). The effects of liming are nearly always positive; however, limestone sand or gravel applied directly to a stream may contribute to the sediment load during high flows.

Reliability and Limitations of Findings

In the last 20 to 30 years, much research has described the mechanism, consequences, and treatment of acidified surface water. The findings are considered highly reliable.

Impacts of liming on water quality have often been studied, and the findings are widely applicable.

Research Needs

In general, knowledge of virtually all of the long-term (more than 20 years) effects of liming on aquatic ecosystems and water quality is lacking. Henrikson and Brodin (1995) compiled a comprehensive list of research questions about liming. In the area of water quality, some of the topics needing particular attention include the effects of liming on the uptake and transport of mercury and other metals in aquatic organisms and the consequences of reacidification if liming is stopped.

Key Point

For treatment of individual small watersheds, current knowledge should permit managers to address most issues related to sources of drinking water associated with liming.

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