Economic Valuation of Ecosystem Services

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INTRODUCTION

According to Mooney and Ehrlich (1997), the idea that humans depend on natural systems dates back as far as Plato, but the first modern publication that addresses this issue is *Man and Nature* by George Perkins Marsh in 1864. He realized that the world's resources were not infinite, and was aware of the importance of natural systems to soil, water, climate, waste disposal, and pest control. In the 1940's, books such as Aldo Leopold's *A Sand County Almanac* (1949), Fairfield Osborn's *Our Plundered Planet* (1948) and William Vogt's *Road to Survival* (1948) brought new attention to the issues addressed by Marsh. The first publication that addressed ecosystems providing "services" to human society is *Man's Impact on the Global Environment* by the Study of Critical Environmental Problems in 1970. They provided a list of "environmental services", which was expanded by Holdren and Ehrlich in 1974. In subsequent publications, these services were referred to as "public services of the global ecosystem" and "nature's services", and were finally coined as "ecosystem services" by Ehrlich and Ehrlich in 1981.

One of the first documents discussing economic valuation of ecosystem services was *Proposed Practices for Economic Analysis of River Basin Projects* by the Committee on Water Resources in 1958 (Bingham et al. 1995). Valuation of ecosystem continued throughout the next decades (de Groot et al. 2002), but research and attention has expanded greatly since two publications helped the subject gain popularity. The first was a book, edited by Gretchen Daily, called *Nature's Services: Societal Dependence on Natural Ecosystems* (1997). This book discusses ecosystem services, their valuation, and provides several case studies. In the same year, Costanza et al. published a controversial paper called "The value of the world's ecosystem services and natural capital." By extrapolating with previous and new data, they came up with a value of $33 trillion for ecosystem services across the globe. Though their methods and result were criticized, the paper served its purpose by bringing attention to and provoking discussion on the topic of ecosystem service valuation.

This paper aims to summarize the current knowledge about ecosystem services and their valuation. It is organized in two sections, the first regarding ecosystem services. It will attempt to find a definition for ecosystem services. This will be followed by a classification, listing, and description of specific services. The classification and description will be on a broad, global level, so it will be followed by a description of ecosystems and the services that are relevant to southeastern Minnesota. Finally, the section will conclude with a discussion about how and why we are losing services.

The second section discusses the valuation of ecosystem services, starting off by describing the different values economists apply to ecosystems. Next is a discussion of the methods used in valuation, followed by examples of valuation studies, specific to Minnesota or the Midwest when possible. Finally, the paper will end by describing some of the issues and limitations of ecosystem service valuation.

I. ECOSYSTEM SERVICES

DEFINITION AND CLASSIFICATION

There is a discrepancy between authors and how they define ecosystem services, particularly in relation to processes and functions. Daily (1997) defines ecosystem services as: "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (p. 3). Here, services encompass functions and processes. Costanza et al. (1997) define functions as "the habitat, biological or system properties or processes of ecosystems" (p. 4). Services, then, are the benefits humans derive from these functions. Here, functions encompass processes, which provide the services. Their table of services is extremely similar to that of De Groot et al. (2002), except that what Costanza et al. call services de Groot et al. call functions. De Groot et al. define functions as "the capacity of natural processes and components to provide goods and services that satisfy human needs" (p. 394). For them, processes lead to functions, which lead to services. Scott et al. (1998) also follow this line of thinking. Processes are "interactions among elements of the ecosystem", functions are "aspects of the processes that affect humans or key aspects of the ecosystem itself...the purposes of the processes" while services are "attributes of ecological functions that are valued by humans" (p. 50).

Practically, the distinction may be arbitrary. Conceptually, however, it is helpful to distinguish between functions and services. Functions are what biologically and chemically occur in ecosystems, and would occur regardless of human presence. Services, however, are based on human needs, uses, and preferences.

The distinction is also helpful conceptually when attempting to organize and classify the myriad of ecosystem services. De Groot et al. (2002) provide a useful classification system. They first delineate four types of functions: regulation, habitat, production, and information. Regulation functions are those that maintain the ecosystems and life support systems. This category consists of bio-geochemical cycles and abiotic-biotic interactions that are important to all living organisms, and directly or indirectly benefit humans. Habitat functions provide habitat for various life cycles of plants and animals, which maintains biological and genetic diversity and the evolutionary process. Production functions consist of the processes that combine and change organic and inorganic substances, through primary or secondary production, into goods that can be directly used by humans. Information functions are aspects of ecosystems that contribute to human mental and spiritual well-being. Because most of human evolution took place in natural systems, our information gathering and sense of well-being are strongly tied to natural landscapes and species. Within each of these functions categories are several specific sub-functions, each of which provide one or more services to humans. The following classification structure is from de Groot et al. (2002) as are the descriptions of sub-functions and services, unless otherwise noted.

<u>Regulation functions</u>

Gas regulation: This function maintains the chemical composition of the air and oceans, including moderating CO_2, O_2, SO_X, and O_3 (ozone) levels. The services provided are clean, breathable air, prevention of diseases such as skin cancer, and general habitability of the earth.

Climate regulation: Regional and global circulation patterns, topography, vegetation, albedo (ability of a material to reflect sunlight), and the location of water bodies all interact to determine weather and climate. Locally, vegetation affects precipitation and temperature. Release of water vapor (transpiration) from leaves influences rainfall, and forests can both provide cooling through shade and insulation by blocking wind and trapping warmth (Daily et al. 1997). This function provides the service of a favorable climate, which is important to human survival and civilization through health maintenance, crop production, recreation, and cultural identity.

Disturbance prevention: Ecosystems can buffer against natural hazards and disruptions. The structure and storage capacity of vegetation can reduce the effects of storms, floods, and droughts, and coral reefs help protect shorelines from wave and storm damage. This provides safety for humans and human structures.

Water regulation: Natural systems influence hydrological cycles and the flow of surface water under 'normal' conditions. This provides maintenance of natural irrigation, drainage, river discharge, channel flow, and transportation mediums.

Water supply: While the flow and cycling of water also influences the water supply, this function relates mainly to the filtration and storage of water. Vegetation and soil filter pollutants from water, while the topography and underground structure of ecosystems determine the storage capacity of lakes, streams, and aquifers. This provides water for human consumption, whether for households, industry, or agriculture.

Soil retention: Soil retention depends on the structure of vegetation and root systems of ecosystems. Roots stabilize the soil and foliage intercepts rainfall, preventing erosion and compaction of the soil. Shoreline and submerged vegetation also prevent erosion and aid in sedimentation. Soil retention allows agriculture to remain productive and prevent damages caused by landslides or dust bowls.

Soil formation: Soil formation is an extremely slow process that occurs through the disintegration of parent rock, accumulation of plant and animal organic material, and the release of minerals. This allows for the productivity of agricultural crops and the general functioning of ecosystems.

Nutrient regulation: The growth and existence of living organisms depends on the availability of nutrients, many of which are in limited supply. That is why recycling of nutrients is very important. Carbon, oxygen, and hydrogen are often cycled through the gas, climate, and water regulation functions mentioned earlier. Nitrogen, sulfur, and phosphorous are other critical elements. Calcium, magnesium, potassium, sodium, chlorine, and trace element such as iron and zinc are also needed. Decomposition by soil organisms releases these elements into the soil and atmosphere so they can be used again. Migration by birds, fish, and mammals also helps spread nutrients between ecosystems. Nutrient cycling provides healthy and productive soil and also influences the gas, climate, and water regulation functions.

Waste treatment: Ecosystems are also able to dilute, assimilate, and chemically re-compose a limited amount of organic and inorganic human waste. Services include air filtration by forests and water purification by wetlands.

Pollination: Insects, birds, and bats can all provide pollination services. Pollination is crucial to plant reproduction, without which many wild plant species would go extinct and current levels of agricultural production would be impossible or very expensive (Daily et al 1997).

Biological control: Biological communities have evolved interactions and feedback mechanisms that allow populations of one or more species to affect the size of another. Through these interactions, populations remain fairly stable, preventing outbreaks of pests and diseases. About 99 percent of crop pests, including insects, rodents, fungi, snails, nematodes, and viruses are controlled by natural enemies such as birds, spiders, wasps, lady bugs, fungi, and viruses, providing a great service to farmers (Daily et al. 1997).

Habitat functions

Refugium function: Natural systems provide living space for plants and animals, allowing for biological and genetic diversity. Wind, water, and animals disperse seeds, and if a seed reaches a suitable spot, the soil shelters and supports it while it grows and matures (Daily et al. 1997). The diversity of plants, then, provide a variety of cover, structure, and food sources that allows a diverse number of animals to thrive. A certain level of biological diversity is essential for maintaining all other functions and services, although the exact relationship is yet unclear (Tilman 1997). In this diversity is stored information from millions of years of evolution, as well as the potential for future evolution. With the possibility of future climate change, genetic diversity, and the evolutionary potential is contains, may become extremely important to the adaptation of plants and animals, allowing them to continue to provide the services we depend on.

Nursery function: Ecosystems also provide breeding and nursery grounds for species that are harvested elsewhere as adults. This function is important for commercial and subsistence uses of many species.

Production functions

Food: Globally, a large amount of food is still provided by wild plants and animals, including fish, fowl, mammals, vegetables, fruit, and fungi. Other foods include nuts, mushrooms, honey, and spices (Daily et al. 1997). Small-scale cultivation is included, as long as it does not interfere with other services.

Raw materials: This category includes biotic renewable resources, such as wood and fibers, biological chemicals and compounds (latex, gums, oils, waxes, dyes, etc.), industrial materials, energy sources (wood, organic matter), and animal feed. Minerals and fossil fuels are not thought of as a service because they are non-renewable, nor are wind and solar energy, because they cannot be attributed to a specific ecosystem.

Genetic resources: Cultivated crops and domesticated animals originated as wild species. For some species, genetic resources of their wild relatives are still needed to maintain productivity or alter characteristics such as taste, pest resistance, or environmental adaptation.

Medicinal resources: Natural ecosystems are important to human health by providing chemicals that are used as drugs or as models for synthetic drugs and by providing animals that are used as tools (leeches) or test specimens.

Ornamental resources: Nature provides many species and objects that have ornamental uses, including: fashion, crafts, cultural objects, pets, decoration, live specimens in zoos and gardens, souvenirs, and collections.

Information functions

Aesthetic information: Most people enjoy natural scenery and landscapes. This is important not just for human enjoyment but can also have economic importance by influencing real estate prices.

Recreation: Natural ecosystems are often used as places for relaxation and recreation, including hiking, camping, fishing, and nature viewing. With increasing wealth and leisure time, recreation also increases. In some areas the demand for recreation provides economic opportunities through eco-tourism.

Cultural and artistic information: Nature is often the basis for cultural traditions and folklore. It provides motivation and inspiration for all forms of art, including books, movies, photography, fine art, music, dance, fashion, and architecture.

Spiritual and historic information: Ecosystems and their elements can provide humans with a sense of continuity and place, and can also be an important part of religion.

Science and education: Natural areas provide numerous opportunities for study, education, and research, as well as references for monitoring environmental change.

These services all interact and depend on each other. Many relationships occur between the four function categories. The regulation and habitat functions often provide the basis for production and information functions (de Groot et al. 2002). The genetic material used in our cultivated crops and medicines would not be available without the refugium function that maintains genetic diversity. The maintenance of biological diversity via the refugium function is important to food, raw materials, ornamental resources, and all the information functions. The nursery function is crucial to many economically important harvested species. Certainly the regulation functions are important in pretty much everything, as the soil, water, nutrients, and climate allow organisms to survive and thrive.

There are also relationships among categories. For example, gas regulation affects the climate, and water regulation affects the water supply (de Groot et al. 2002). Soil retention influences water supply, water regulation, and disturbance regulation by soaking up water, reducing runoff, and keeping navigable water channels clear. Soil retention is also crucial to nutrient regulation (Daily et al. 1997).

MINNESOTA ECOSYSTEMS

The numerous services mentioned above are present throughout the world. Not all ecosystems will provide all those services, and some services are more prevalent in certain ecosystems. Though all four function categories will be present, many services will be site specific. For policy-making and planning, it is important to know what the important services provided by local ecosystems are. Following is a description of ecosystem found in southeast Minnesota and the most important services provided by each.

According to a map created in 1930, the original vegetation of southeast Minnesota consisted primarily of oak woodland and brushland, followed by upland prairie, maple-basswood forests, floodplain forests, and some prairie wetland. Unfortunately, most of that native vegetation was converted to agriculture or urban areas. Less than one percent of Minnesota's prairies remain (Tester 1995). It is estimated that in 1993, between five and ten percent of the land in Winona County was covered by natural communities, and in 1992 only seven percent of the land in Goodhue County was covered by natural communities (Minnesota County Biological Survey [MCBS] 1994a and 1994b).

The MCBS has published maps for six counties in southeast Minnesota: Goodhue, Fillmore, Houston, Olmsted, Wabasha, and Winona. These maps show the specific type and location of native communities, and for all counties but Goodhue provide acreage as well. They also list rare plant and animal species found in each county (see appendix). The most numerous communities include oak forest, maple-basswood, lowland hardwood, and floodplain forests, dry oak savannas and prairies, and a variety of swamps, marshes, and wet meadows, although other communities are present. For a detailed description and key to these communities, see *Minnesota's Native Vegetation: A Key to Natural Communities* published by the Minnesota Department of Natural Resources (1993). The following descriptions of forest, prairie, and freshwater ecosystems in Minnesota are taken from Tester (1995).

Forests

Maple-basswood forests are named for the two dominant species: sugar maple and basswood. Other tree species include elm, red oak, ironwood, ash, butternut, and bitternut hickory. The understory is relatively sparse because the heavy canopy shades most of the sunlight. Sugar maple seedlings, red-berried elder, choke cherry, pagoda dogwood, and prickly ash compromise the shrub cover. Herbaceous plants such as trillium, bellwort, bloodroot, and violets are most numerous in the early spring, before the tree leaves shade them out. There are a few summer herbs, such as zig-zag goldenrod, ferns, and wood nettles. Rare species include American ginseng and dwarf trout lily. The trout lily can be found in Goodhue County, one of the only two counties it is found in on the planet.

Oak forests contain at least 30% oak species, including red, white, and bur. Oak forests on dry, sandy soil probably originated from oak savannas where fire was suppressed. Oak forests on moist soil may progress to maple-basswood forest.

Lowland hardwood forests occur where soil is occasionally saturated. Tree species include black ash, elms, basswood, bur oak, hackberry, yellow birch, green ash, aspen, and paper birch.

Another type of forest occurs in the seasonally flooded soils of river floodplains. Young floodplain forests may contain black willow and cottonwood, while mature forests consist of American elm, black and green ash, silver maple, and swamp white oak. These species are tolerant of flooding, floating debris, ice, and siltation.

Along the border between deciduous forest and prairie is where oak savannas, woodlands, and brushlands occur. These communities consist of sparse trees and shrubs with a prairie understory.

There are numerous animal species that live in these deciduous forest types. Mammals include white-tailed deer, cottontail rabbits, woodchucks, twelve species of bats, ground squirrels, flying squirrels, chipmunks, raccoons, skunks, opossums, gray and red fox, and many species of mice and voles.

In upland forests, common bird species include broad-winged hawk, barred owl, yellow-bellied sapsucker, hairy woodpecker, white-breasted nuthatch, red-eyed vireo, and ovenbird. In moist and floodplain forests can be found red-shouldered hawks, eastern screech owls, tufted titmice, northern orioles, wood thrushes, and scarlet tanagers. Red-tailed hawks, great horned owls, red-headed woodpeckers, brown thrashers, and indigo buntings can be found in oak savannas and woodlands. Game species include wild turkeys and ruffed grouse.

Amphibians and reptiles are most abundant in southeastern Minnesota; 77% of the species found in Minnesota occur in the southeast. The most common species are the gray treefrog and the garter snake. Rare species include the timber rattlesnake, massasauga, and gopher snake.

The forests are also home to a variety of invertebrates, as well, including the all-too-common mosquito, wood tick, and deer tick.

Prairie

Tallgrass prairies are classified into three categories based on soil moisture: mesic, dry, and wet. Mesic prairie, with moderate soil moisture, is characterized by five grass species: big bluestem, little bluestem, Indian grass, prairie dropseed, and porcupine grass. Common forbs in southeastern mesic prairies are wild false indigo, rattlesnake master, compass plant, wild quinine, and Indian plantain.

Dry prairie vegetation, found on sandy or gravel soil, includes little bluestem, sideoats grama, prairie dropseed, June grass, needle grass, pasque flower, prairie smoke, compass plant, purple coneflower, and silky aster. This vegetation is sparser and shorter than mesic prairies. Wet prairie vegetation includes many sedges, prairie cord-grass, switchgrass, mat muhly, big bluestem, wild licorice, white lady slipper, New England aster, and golden alexanders. This vegetation is usually dense and tall, and may blend with wetland species.

Prairie vegetation is well adapted to sustain fires, drought, and grazing. These disturbances help maintain prairies by suppressing tree growth.

Mammal species found on prairies include gophers, badgers, red fox, coyotes, skunk raccoon, mice, voles, and shrews. Some prairie bird species are marbled godwits, upland sandpipers, meadowlarks, bobolinks, savannah sparrows, red-wing blackbirds, short-eared owls, and northern harriers. Rare species include the prairie chicken and burrowing owl. Amphibians and reptiles include western chorus frogs, leopard frogs, Manitoba toads, tiger salamanders, prairie skinks, plains garter snake, western hognose snakes, and gopher snakes. Many insects depends on prairie habitat, such as monarch butterflies, bees, grasshoppers, crickets, and beetles.

Freshwater

Wetlands: Wetlands are delineated into five main zones. The outermost is the low-prairie zone, which may become flooded in the spring but otherwise does not contain standing water. Vegetation here includes cutgrass, blue-joint grass, sedges, mints, and asters. The next zone, the wet-meadow zone, has very moist soil and some standing water. Vegetation includes spike rush, bur-reed, several rushes, and water hemlock. The shallow-marsh zone follows, with standing water a few inches to a few feet in depth. Here vegetation consists of cattail, bulrush, reed, and some floating-leaved and submerged plants. Much deeper water, up to eight feet, is found in the deep-marsh zone. There are few emergent plants but many are floating-leaved and submerged plants, such as pondweeds, coontail, bladderwort, yellow water-crowfoot, and sago pondweed. The final zone is the open-water zone, which is too deep for rooted plants but can contain algae and duckweeds.

Not all five zones are found in all wetlands; it depends on the contour and water depth. Furthermore, water levels fluctuate throughout the year, with higher levels in the spring and during abundant rainfall and low to dry levels during the summer, fall, and drought periods.

Mammals that use wetlands include muskrat, beaver, meadow voles, mink, and raccoon. A large number of waterfowl species can be found in wetlands, including mallards, pintails, blue-winged teal, canvasbacks, redheads, lesser scaups, pied-billed grebes, great blue herons, great egrets, sandpipers, plovers, and red-winged blackbirds. Wetland amphibians and reptiles include fourteen species of frogs and toads, such as chorus frogs, spring peepers, and green frogs, as well as tiger salamanders, painted turtles, snapping turtles, and the threatened Blanding's turtles. Wetlands are not the best habitat for fish, but small species such as fathead minnows, brook sticklebacks, and bullheads can be found. Many invertebrates also live in wetlands, including snails, clams, worms, crustaceans such as crayfish, and insects such as midges, dragonflies, and damselflies.

Lakes: Lakes are comprised of three zones: the littoral, pelagic, and profundal zones. Not all of these zones will be present, and their proportions depend on size of the lake, the shape of the shoreline, and the contour of the basin.

The littoral zone is the shallowest part of a lake, where rooted plants can grow. Emergent plants occur closest to the shore, followed by floating-leaf plants in deeper water and submerged aquatic plants in deep water until light can no longer penetrate. Snails, insects, muskrats, and carp feed on littoral vegetation, while adult fish feed on the insects. Insects that live in the littoral zone include caddis fly larvae, water boatmen, diving beetles, and dragonfly larvae.

The pelagic zone is too deep for rooted plants, but still receives enough light, allowing thousands of algae species to survive. Algae are often grouped into blue-green, green, and brown categories. Zooplankton, such as cladocerans, copepods, rotifers, fairy shrimp, scuds, and amphipods feed on the algae. These zooplankton are in turn eaten by larger consumers, such as fish. Some organisms are found on the very surface of the pelagic zone, such as duckweed, spiders, whirlygigs, and water striders.

The profundal zone includes the sediment and water where light does not penetrate. No plants are present, so the bacteria, protozoa, and invertebrates that live here feed on plant and animal excrement and dead organisms. The invertebrates may include annelids, oligochaetes, and leeches. Fish that feed on these organisms will also be present.

These zones are based on amount of light, but many other physical and chemical characteristics of lakes greatly influence what organisms will live there. Incoming surface and ground water, topography, soil, vegetation, and land use of the surrounding watershed can affect water chemistry. Important chemical characteristics include hardness, alkalinity, pH, phosphorus, sulfate, nitrogen, oxygen, and dissolved organic matter. Phosphorus and nitrogen are the main limiting factors for aquatic vegetation. Stratification, the formation of layers of water of different temperatures, and water movement are also important.

Lakes are often classified as oligotrophic, mesotrophic, eutrophic, or hypereutrophic. Oligotrophic lakes have lower nutrients, few algae, clear, deep water, and high oxygen levels. Eutrophic lakes have high nutrients and algae, shallow water, and limited oxygen. Mesotrophic lakes are between the two, and hypereutrophic lakes have even more nutrients and algae than eutrophic ones.

Fish species are most affected by these lake types. Lake trout, whitefish, and stream trout are found in oligotrophic lakes. Mesotrophic lakes are home to walleye, sauger, yellow perch, northern pike, and muskellunge. Sunfish, crappies, largemouth bass, catfish, and bullheads are the most common fish in eutrophic and hypereutrophic lakes.

Amphibians and reptiles that can be found in or near Minnesota lakes include green frogs, mudpuppies, northern water snakes, mink frogs, snapping turtles, and painted turtles. Raccoons, minks, deer, coyote, beaver, and muskrats are some of the mammals that use lake habitat. Many birds can also be seen in or near lakes, such as swallow, purple martins, eagles, osprey, terns, white pelicans, mergansers, lesser scaups, grebes, loons, herons, and egrets.

Rivers and streams: Rivers and streams are part of larger systems of drainage basins. Small streams empty into larger ones, which empty into river branches, which eventually empty into the main river stem. These streams and rivers are classified by order. A first order stream is small with no tributaries. Two first order streams join to form a second order stream. It takes two streams of one order to make a stream of the next order; most will be less than ten, which is the order of the Mississippi River. There are eight major drainage basins in Minnesota. Southeast Minnesota is part of the largest, the Mississippi River Basin.

The physical characteristics of rivers and streams may be more important than biological ones. These physical attributes include the shape, length, slope, and streambed composition of the channel, and the discharge rate, velocity, turbidity, and temperature of the water. Important chemical parameters include hardness, pH, alkalinity, nitrogen, and oxygen.

These physical and chemical characteristics determine what organisms will be found there. Almost all stream and river organisms have adaptations to deal with moving water. These adaptations can be behavioral, physiological, morphological, or anatomical methods to deal with feeding, mating, egg laying, moving, or not moving in the rapid water. River organisms are often classified into groups based on how they deal with moving water; these groups include fixed or sedentary organisms that live on the bottom, drifting organisms, surface floating organisms, and active swimmers.

Vegetation in rivers and streams is usually sparse. Sedentary vegetation is mostly algae and moss, often in a filamentous form, which is attached to rocks. Algae can also be found drifting, while duckweeds float on the surface. Most plant material comes from leaves, twigs, and other plant material that falls or is washed into the water.

Invertebrates are so abundant and varied that further classification is useful. Herbivores are separated based on how they feed on living or dead plant material: shredders, collectors, scrapers, and piercers. Shredders consume vegetation, collectors filter particles using hairs, bristles, or nets, scrapers use mouthparts to scrape algae and moss from rocks, and piercers suck juices from plant cells. Other invertebrates are predators, feeding on the herbivores.

The proportion of herbivore types and predators changes based on the stream section. At the headwaters, collectors are most abundant and include blackfly larvae and mayfly nymphs. Shredders, such as caddis fly larvae, crane fly larvae, and stone fly nymphs, are close behind. There are a few predators, such as the dobsonfly larvae. In the middle of a stream or river, shredders are very few, while collectors are still abundant. Scrapers, such as snails, limpets, and some species of mayfly nymphs, are abundant as well. The most common predator is the dragonfly nymph, but is still in smaller numbers. In the lower reaches, shredders and scrapers are very few, while collectors such as mussels, cladocerans, copepods, and bloodworms are extremely abundant. A few predators, such as the backswimmer, are also present.

In cool, clear streams, fish species such as trout and smallmouth bass can be found. In the lower reaches, catfish, paddlefish, and sturgeon are common. Many small fish are common as well, such as minnows, darters, and sculpins. Many streams in southeastern Minnesota are cold-water trout streams that support brown trout, rainbow trout, white suckers, and dace.

Amphibians and reptiles including bullfrogs, pickerel frogs, green frogs, leopard frogs, map turtles, and softshell turtles live in or near rivers and streams. The most common bird species associated with rivers is the belted kingfisher, but many lake and wetland bird species can also be found. Common mammals include beavers, mink, otters, muskrats, raccoons, and water shrews.

<u>Services of Minnesota communities</u>

All of these communities provide a habitat function, allowing the diversity of species in Minnesota to survive. Each of these communities can also provide many information functions, such as aesthetic beauty, artistic and spiritual information, and science and education opportunities. Recreation, such as hunting, fishing, hiking, boating, camping, and wildlife viewing can be provided by all communities, as well, but are most likely in forests, lakes, and rivers.

Terrestrial: The soil and vegetation of forests and prairies provide many services. Soil, and the vegetation protecting the soil, filter water and allow it to infiltrate the ground instead of runoff into rivers and streams. Soil is also critical to nutrient cycling and waste decomposition (Daily et al. 1997). The Decorah Edge is an upland forest ecosystem, underlain by shale bedrock, which runs through Goodhue, Olmsted, Winona, Fillmore, and Houston counties. The groundwater in this system provides drinking water to 18 communities in southeast Minnesota. The Decorah Edge ecosystem provides an important water filtering service, especially since some of the land has been converted to agriculture (Lee 2003). Both forests and prairies can hold, or sequester, carbon in their vegetation and soils, removing carbon from the atmosphere and contributing to the mitigation of global warming (Myers 1997a; Sala and Paruelo 1997).

Specific to forests, basswood, slippery elm, black cherry, and especially sugar maple are important to nutrient regulation. These species do not move nutrients from their leaves to their trunks in the fall. When the leaves are dropped, those nutrients are decomposed and returned to the soil. This produces and maintains fertile soil that has good drainage and some water holding capacity, enhancing water supply services.

Sugar maples also provide a production function in the form of sap used for maple syrup. Wild ginseng is used for medicinal purposes, which has unfortunately led to declining populations. Bats benefit humans by feeding on a large number of insects. They have also been used for scientific and medicinal research (Tester 1995).

Freshwater: The services provided by wetlands are extensive. They contribute to gas regulation by removing carbon dioxide, sulfur dioxide, and nitrous oxide from the atmosphere. The contribute to the water supply by removing contaminants such as heavy metals, pesticides, nitrogen, and phosphorus. They help regulate water flow by recharging streams and aquifers. The flood control function is also very valuable (Tester 1995).

The littoral vegetation of a lake is responsible for filtering silt, nitrogen, phosphorus, and other nutrients from incoming water. This zone also provides a nursery habitat function by providing cover for small fish that may be games species as adults (Tester 1995). Lakes also provide water for drinking, manufacturing, and agriculture (Postel and Carpenter 1997).

Rivers also supply water for drinking, manufacturing, and agriculture and are used for hydroelectricity, although that often alters the stream ecosystem (Postel and Carpenter 1997). Rivers and their floodplains provide the services of pollution dilution, runoff regulation, flood control, sediment transport, and organic matter processing and recycling (Strange et al. 1999).

Though most of Southeast Minnesota is no longer covered by native vegetation, the converted areas are not devoid of ecosystem services. Ecosystems within urban areas continue to provide some services, especially if planned for, although certainly to a lesser extent than continuous, more natural systems. Bolund and Hunhammar (1999) identified seven urban 'ecosystems': street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes, and streams. Street trees are single trees usually surrounded by pavement. Lawns/parks are managed areas with a mixture of trees, grass, and other plants, including playgrounds and golf courses. Urban forests are less managed with denser trees than a park. Cultivated land is area used to grow food, including gardens. Wetlands include marshes and swamps, lakes are open water areas, and streams have flowing water.

The vegetation of these systems, particularly of trees, filters pollution from the air. The urban climate is also affected; water helps even out summer and winter temperatures, trees lower summer temperatures by using energy for transpiration, and vegetation lowers heating and cooling costs by proving shade and windbreaks. Vegetation and soft ground (including lawns and parks) reduce noise and block the view of traffic. Soft ground also provides natural water drainage; impervious surfaces such as roofs, streets, and parking lots increase runoff and require expensive storm drainage systems. Wetlands can be used to treat sewage water. Finally, all of these ecosystems provide aesthetic, cultural, and recreation services, helping city dwellers with hectic lifestyles slow down, relax, and relieve stress.

LOSS OF SERVICES

Humans, like all organisms, must use and change their environment to survive. However, the activities of humans are widespread and often severe, causing negative and often permanent losses to ecosystems and the services they provide. In general, population growth, increased demand for resources, pollution, and land conversion to agriculture and urban areas cause loss of habitat, species, and services.

More specifically, burning fossil fuels and clearing forests, especially tropical forests, alter gas and climate regulation (Alexander et al. 1997). Postel and Carpenter (1997) describe eleven activities that decrease the provision of water supply, flood control, transportation, and recreation services of freshwater systems. Among these activities are dam, dike, and levee construction, water diversion, wetland drainage, deforestation, and pollution. Deforestation, overgrazing, and poor cultivation practices negatively impact soil regulation and formation (Daily, Matson, and Vitousek 1997).

Poor agricultural practices negatively impact many other ecosystem services. Soil erosion causes sediments, and the farm chemicals they carry, to enter streams and lakes, harming aquatic organisms and decreasing their flood control capabilities (Pimentel et al. 1995). The conversion of land in combination with modern farming methods has caused massive habitat loss, including wetlands and grasslands, and is the main factor in low wildlife populations in North America (Feather, Hellerstein, and Hansen 1999).

Many of the negative impacts of agriculture are due to pesticide use. Insecticides and fungicides kill pest species, but they also kill predators and pathogens that naturally control pest populations. Pesticides are very harmful to wildlife by poisoning animals or the food they eat. This includes sport and commercial fish species, wild birds, microorganisms, and invertebrates, especially important pollinators, such as bees (Pimentel et al. 1992).

Pesticide use is not the only thing leading to the loss of pollinators. Habitat fragmentation, habitat loss, grazing, loss of plant diversity, herbicide use, disease, and competition from exotic species have all led to what is now called a pollination crisis (Kearns, Inouye, and Waser 1998; Nabhan and Buchmann 1997).

According to Pimentel et al. (2000), the invasion of exotic species impacts services provided by many different organisms. Non-native species can be introduced intentionally or accidentally. Not all non-natives become problems, and some are quite beneficial. However, some become invasive and displace native species through competition or predation. Some exotic plant species can take over entire ecosystems. Invasive species are present in many animal categories, including mammals, birds, fish, amphibians, reptiles, mollusks, and arthropods. Many problematic diseases and pathogens are also considered exotic species. All invasive species greatly alter native ecosystems, which can jeopardize the services provided.

Daily et al. (1997) point out that there are deeper problems that encourage the activities mentioned above. The human population is growing very rapidly, both in size and consumption levels. The greater number of people with their growing demand for land and goods will mean that the destructive activities will also grow. Another problem is the disparity between short-term, individual economic benefits and long-term, societal good. In these short-term decisions, ecosystem services are usually undervalued. This occurs because most ecosystem services are not valued in the market, most landowners cannot benefit financially from the services their land provides, and government subsidies often encourage land conversion.

II. VALUATION

TYPES OF VALUES

There are two ways that something can be valuable: instrumentally or intrinsically. Instrumental (or utilitarian) means that something has value because it is useful to something else. Intrinsic means that something has value in and of itself, not because something else deems it valuable. In environmental philosophy, these two values can be ascribed from three different viewpoints: ecocentric, biocentric, or anthropocentric. In an ecocentric viewpoint, ecosystem processes have intrinsic value while individual species have instrumental value. Biocentrists hold that animals and plant have intrinsic value while non-living nature has the instrumental value. With anthropocentrism, only humans have intrinsic value, while everything else (i.e. nature) has instrumental value (Meffe and Carroll 1997).

The economic approach to ecosystems is one of anthropocentric instrumentalism. Ecosystems and their services are valuable if they serve and satisfy human beings. Many environmentalists would immediately recoil at this thought, asserting that nature has intrinsic value. However, anthropocentric utilitarianism does not necessarily mean that ecosystems must be exploited and have no value in their natural states (Goulder and Kennedy 1997). There is a range of values, many of which are presented by intrinsic rights proponents (Toman 1997). It is also important to realize that the economists' utilitarian values can, at least in theory, be measured and quantified, while intrinsic values cannot (Brown et al. 1993).

Economists divide values into two main categories: use and non-use (Figure 1). Use values are derived from physical involvement with some aspect of an ecosystem. One type of use value is direct, such as logging, fishing, recreation, and tourism, while another is indirect. Direct use is further divided into consumptive (logging, fishing) and non-consumptive (recreation, tourism) values. There are also indirect use values, which arise from supporting humans or what humans directly use. Regulation and habitat functions, such as flood control, climate regulation, and waste assimilation would fall into this category (Adamowicz 1991; Brown et al. 1993; Edwards and Abivardi 1998; Goulder and Kennedy 1997).

Non-use values do not involve physical interaction. This includes existence, bequest, and option values. Existence value (sometimes called passive use) is derived from the satisfaction of knowing that a certain species or ecosystem exists, even if it will never be seen or used. Bequest value is satisfaction from being able to pass on environmental benefits to future generations (Adamowicz 1991; Edwards and Abivardi 1998). Option value pertains to the possible use of a resource in the future. This has to do with uncertainty and risk-aversion. An example is the preservation of tropical rainforests because we may be able to find new medicines. (Adamowicz

1991; Brown et al. 1993; Edwards and Abivardi 1998; Goulder and Kennedy 1997). See Table 1 to see how these values relate to the ecosystem functions mentioned previously.

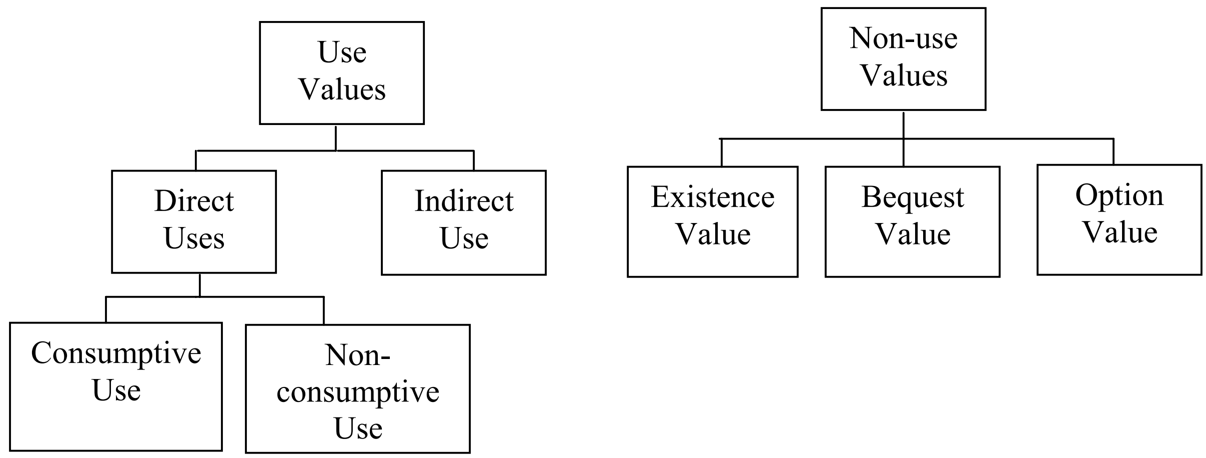

Figure 1: Types of values (adapted from Edwards and Abivardi 1998)

METHODS FOR VALUATION

Many of the values described above are abstract and subjective. These values play a big part in what people get from the natural world and why they want it to be preserved. However, only a small portion has any sort of presence in economic markets. When land use decisions and policies are being made, usually only the economic values are taken into consideration, and the other values are undervalued or ignored. For this reason, great effort has been made to somehow put a dollar amount on the values that are not represented in markets.

Economic theory is based on the premise that individuals have preferences for different market and non-market goods. These preferences have a degree of substitutability; if the quantity of one good is reduced, the quantity of a different good can be increased to leave the person no worse off. The trade-offs made during this substitution reveal something about the values held for each good. Measurements of these values are expressed as either willingness to pay, the maximum amount a person would be willing to pay for an increment of a good, or willingness to accept, the minimum amount a person would require as compensation for the loss of an increment of a good (Freeman 2003).

Methods for measuring these values fall into two categories: revealed preference and stated preference. Revealed preference measurements are based on observations of actual behavior, while stated preference measurements are based on responses to hypothetical questions (Freeman 2003).

Direct market valuation is one type of revealed preference, and can be used for those few services that are traded in the market. This includes the production function category, such as food, raw materials, and some recreation values. The value of the service is the market price (de Groot et al. 2002). However, most ecosystem services have no direct presence in our economy. In that case, a price may be derived indirectly through related factors that do have a market. There are many indirect market valuation techniques. The less common ones include household production costs (costs of cleaning or repair due pollution), avoided cost (costs that would have incurred if the service were absent, such as flood control), replacement cost (the cost of replacing a service with a man-made system), factor income (how much a service enhances income, such as for commercial fishermen), dose-response (how changing an environmental service affects the production costs of a product), and averting behavior (expenditures to defend against negative effects of pollution, such as sunscreen sales) (de Groot et al. 2002; Freeman 2003; Hoevenagel 1994).

Far more common are the travel cost and hedonic pricing methods. The travel cost method estimates the value of a recreational site or changes in the environmental quality of that site by using the amount of money and time people spend traveling there. It tries to find out the willingness to pay for recreational services (Adamowicz 1991; Hoevenagel 1994; Toman 1997). This method is advantageous because it relies on observed behavior and can provide a behavioral model that can be tested for accuracy. However, there are some disadvantages, as well. Behavioral assumptions must be made by the researcher, which may not accurately reflect how an individual decided to visit a site. The value and opportunity costs of the time it takes to travel are very important, even more so than the cost of travel. The time issue, however, is much more difficult to measure. Also, this method can only be applied to use values, so if it is the only method used for a site valuation the benefits may be underestimated (Adamowicz 1991; Hoevenagel 1994).

The hedonic pricing method is based on the idea that people prefer and will pay more to live in areas with good environmental quality. The value of environmental quality, then, is embedded in housing prices (Hoevenagel 1994). As with the travel cost method, the hedonic pricing method is advantageous in that it uses observed market behavior, but it, too, has problems. This method requires many assumptions that usually do not hold in reality, such as that each household is aware of the effects of pollution and is able to buy exactly what housing characteristics it wants. This method is also disadvantageous because some pollution effects may not be clear to the household, data collection and statistical analysis can be difficult, and it is limited to use values (Adamowicz 1991; Hoevenagel 1994).

Stated preference methods, again, draw values from responses to hypothetical questions. The main method for this is contingent valuation, which is widely used and widely discussed. Contingent valuation directly asks individuals about the values they place on environmental services via a survey or questionnaire. It is quite useful in that it can be used to value a wide array of services, and for some, such as existence values, it is the only method possible. However, this flexibility also leads to methodological challenges and questions of bias and reliability (Bishop and Heberlein 1990; Hoevenagel 1994b).

The survey design is very important. The first step is to define the population whose values are to be measured, such as park visitors, hunters, or community members. Then, as with all surveys, a sound sampling strategy must be designed (Bishop and Heberlein 1990). Next the questionnaire itself must be written. In order to obtain realistic values, the respondents must have a good understanding of the ecosystem service or environmental quality changes they will be asked about, of the hypothetical method of payment (i.e. taxes, licenses, fees), and of the social context of the payment. Ideally, these hypothetical situations will be realistic, but also neutral. The goal is that the values expressed by the respondents are those held for the ecosystem service, and do not reflect other issues, such as dissatisfaction with tax rates (Bishop and Heberlein 1990; Hoevenagel 1994b).

Once the respondent understands the hypothetical situation, they can be asked valuation questions. There are several options for the question format. One is the referendum format, where a person is asked if they would be willing to pay $X for a policy, program, or environmental improvement. Direct open-ended questions allow respondents to come up with their own amount they would be willing to pay, without any starting point provided by the practitioners. This format is often seen as less reliable, because it is difficult for respondents to come up with a realistic value out of the blue. Another format is the bidding game, where a respondent is asked if they would pay $X. If the answer is yes, then they are asked if they would pay a higher amount, until the highest amount they would be willing to pay is reached. If the answer is no, the amount is lowered until it reaches an amount the respondent would be willing to pay. This format helps respondents give more consideration to their answers. However, this type of question can only be used with phone surveys, an expensive and time consuming approach. The payment-card method provides a card that has several dollar amounts from which respondents can choose their willingness to pay. The payment-card method, however, can be used in mail surveys. Finally, with the contingent ranking methods, respondents are asked to rank alternatives of environmental quality and services without placing monetary values on them. It is still debated which of these methods is best, but the format choice usually depends on the type of service being examined and the information desired (Bishop and Heberlein1990; Freeman 2003; Hoevenagel 1994b).

As was alluded to previously, there are some issues surrounding contingent valuation. One is the validity of responses. Would respondents actual pay the amount the say they would? Some may even give a value of zero, because they feel they should not have to pay for something they feel they have a right to (Freeman 2003). Most people are unfamiliar with ecosystem services, and even more unfamiliar with placing monetary value on them, so answers may be more of a guess than their true willingness to pay (Hoevenagel 1994). There are no market values to test the validity of contingent valuation responses, but there are some indirect methods available. These methods are still being researched and tested, but show promise (Bishop and Heberlein 1990).

The potential for biased answers is another issue. There are four main sources of bias: sampling design, incentives to misrepresent willingness to pay values, implied value cues, and scenario misspecification (Hoevenagel 1994b). Sampling design refers to issues of representative samples and nonresponses that are common to all surveys (Freeman 2003). There are several biases that can result from respondents' incentives to misrepresent their willingness to pay. One is strategic bias, where respondents provide misleading answers to serve their own purposes. These purposes include the fear that fees will actually be assessed, and so will give low values, or the feeling that the values will promote a desired service or policy, and so will provide high values (Bishop and Heberlein 1990). Two other incentive biases are interviewer bias, where misleading answers are given to please the interviewer, and social-desirability bias, where a respondent gives an answer they think will make them look good. Three implied value cues are starting point bias, where values are based on the starting point in a bidding game, range bias, when values are based on the range of values provided by a payment card, and relational bias, when values are based on the value of some related public good. Scenario misspecification biases result when respondents misperceive the hypothetical situations. Most of these biases can be overcome with careful survey design, question format selection, and result analysis (Hoevenagel 1994b).

Another stated preference method that has only recently been gaining attention is the group valuation, or discourse-based valuation. In this method, a group of stakeholders is brought together to discuss values of ecosystem services (de Groot et al. 2002; Wilson and Howarth 2002). Ecosystem services are public goods, and decisions regarding them affect many people. For this reason, many feel that the valuation of these public services should not come from individual-based values, such as the previous ones, but from public discussion. The values derived would be society's willingness to pay or accept, rather than an individual's. This should lead to more socially equitable and politically legitimate outcomes (Wilson and Howarth 2002). Group valuation is not, however, a replacement for individual-based methods. Kaplowitz (2001) and Kaplowitz and Hoehn (2001) compared results from individual and group valuation methods. Both studies found that the two approaches yield different answers and values, and are complementary rather than interchangeable. This method has challenges like all the others. Failure of groups members to share all their information and group dynamics such as peer pressure or a dominant member can lead to incomplete or biased results (Kaplowitz and Hoehn 2001; Wilson and Howarth 2002).

The valuation method used will depend on what type of service is being studied. In general, regulation functions have been most often valued with avoided cost or replacement cost methods, habitat functions with direct market (such as money donated for habitat protection), production functions with direct market or factor income, and information functions through contingent valuation (cultural and spiritual information), hedonic pricing (aesthetic information), or market pricing (recreation, tourism, and science) methods. However, many different methods can work for any given service (Table 1), and the method of choice depends on the specific characteristics and goals of the study (de Groot et al. 2002).

VALUATION EXAMPLES

There is an extensive number of valuation studies that have been performed. There are hundreds available for the contingent valuation method alone (Bishop and Romano, 1998). Following is a sample of values found in the literature, with an attempt at providing values for a range of services and using a variety of methods. I have taken values from the literature and placed them in the list according which service fits best, but many studies include several services. The most local studies (Minnesota and nearby states) are listed first. Prices are in US dollars of the year of the study unless otherwise noted.

<u>Regulation functions</u>

Gas regulation

- Global: to replace the carbon storage function of tropical forests would cost $3.7 trillion (Panayotou and Ashton 1992 via Myers 1997).
- Global: the value of carbon sequestration in grasslands is $200 per hectare (Sala and Paruelo 1997).

Climate regulation

- (microclimate) Chicago, Illinois: an increase in tree cover of 10% can reduce heating and cooling costs by $50-90 per dwelling per year (McPherson et al. 1997 via Bolund and Hunhammar 1999).
- California: individual willingness to pay for the abatement of an increase to a mean summer high temperature of 100 degrees F is $140 (Alexander et al. 1997).

Table 1: The relationship between functions, values, and valuation methods. The application of valuation methods is taken from de Groot et al. 2002. Common methods are the methods that have been used most often for a particular function in the literature; possible methods are methods that are not used often but potentially could be. DM= direct market, AC= avoided cost, RC= replacement cost, FI= factor income, TC= travel cost, HP= hedonic pricing, CV= contingent valuation, and GV= group valuation. *All of these functions have bequest value, so for space sake bequest has not been written in each cell. It is possible that all have existence value, as well, but I have put existence value with functions that make the most sense to have existence value.

ECOSYSTEM FUNCTION	VALUES*	COMMON METHODS	POSSIBLE METHODS
REGULATION FUNCTIONS			
Gas regulation	Indirect use	AC	RC, FI, CV, GV
Climate regulation	Indirect use	AC	RC, FI, CV, GV
Disturbance prevention	Indirect use	AC, RC, CV	FI, HP, GV
Water regulation	Indirect use	FI, AC, DM	RC, HP, GV
Water supply	Indirect use	DM, RC	AC, FI, TC, HP, CV, GV
Soil retention	Indirect use	AC, RC	FI, HP, CV, GV
Soil formation	Indirect use	AC	RC, FI, CV, GV
Nutrient regulation	Indirect use	RC	AC, FI, CV, GV
Waste treatment	Indirect use	RC, CV	AC, FI, HP, GV
Pollination	Indirect use	RC, FI, AC	DM, CV, GV
Biological control	Indirect use	RC, FI, DM	AC, CV, GV
HABITAT FUNCTIONS			
Refugium function	Indirect use, existence value	DM, CV	RC, FI, HP, GV
Nursery function	Indirect use	DM	AC, RC, FI, HP, CV, GV
PRODUCTION FUNCTIONS			
Food	Direct consumptive use, option value	DM, FI, CV	RC, GV
Raw materials	Direct consumptive use, option value	DM, FI, CV	RC, GV
Genetic resources	Direct consumptive use, option value	DM, FI	RC, CV, GV
Medicinal resources	Direct consumptive use, option value	DM, FI	AC, RC, CV, GV
Ornamental resources	Direct consumptive use,	DM, FI	RC, HP, CV, GV
INFORMATION FUNCTIONS			
Aesthetic information	Direct non-consumptive use, existence value,	HP	RC, TC, CV, GV
Recreation	Direct non-consumptive use, existence value,	DM, CV, FI, TC, HP	RC
Cultural and artistic information	Direct non-consumptive use	CV	DM, FI, TC, HP, GV
Spiritual and historic information	Direct non-consumptive use, existence value,	CV	TC, HP, GV
Science and education	Direct non-consumptive use	DM	FI, TC, CV, GV

Disturbance prevention

- Mud Lake, MN/SD: the avoided costs due to natural flood control is $440 per acre per year
- ($2.2 million per year) (Roberts and Leich 1997).
- Minnesota: the federal expenditure to Minnesota for the 1993 Midwest flood was $573.1 million (Alexander et al. 1997).
- Boston, MA: flood protection of a wetlands complex provided an annual savings of $17 million (Hair 1988 via de Groot 1992).

Water supply

- Rochester, MN: the cost to remove nitrate contamination from water was $2.8-$4.8 million annually (Pottebaum 1990).
- Southwestern MN: communities are willing to pay $2.4, $2.0, $6.6, and $2.6 million annually for water quality improvement in the levels of iron, sulfate, hardness, and copper respectively (contingent valuation method) (Cho 1996)
- Mud Lake, MN/SD: natural water supply provides $94 per acre per year ($94,000 per year) in public utility revenues (Roberts and Leich 1997).
- Minnesota: residents living near the Minnesota River were willing to annually pay $14.07 via taxes or $19.64 via water bills for a 40% decrease in phosphorus levels in the river (contingent valuation method) (Mathews et al. 1999).
- St. Louis, Missouri: increased reservoir water quality and surface area provides an annual net benefit of $\$25x10^6$ (1997 dollars, travel cost method) (Burt and Brewer 1971 via Wilson and Carpenter 1999).
- Milesburg, Pennsylvania: the value of the water supply is between $14 and $36 per household (avoided cost) (Laughland et al. 1996 via Nunes and van den Bergh 2001).

Soil retention.

- Southeastern Minnesota: recreation and damage costs due erosion causing the loss of surface water on the Mississippi River backwater pools range from $79,572 to $668,228 annually (Wen 1986).
- United States: Conservation Reserve Program land provides $227.5 million per year in soil productivity benefits (Young and Osborn 1990 via Feather et al. 1999).
- United States: on and off site costs of soil erosion are $44 billion per year (Daily et al. 1997).
- Palouse region, US: soil erosion causes $4 and $6 per acre losses to agriculture (production function method) (Walker and Young 1986 via Nunes and van den Bergh 2001).

Soil formation

- United States: the total value of biotic activity contributing to soil formation on agricultural land is $5 billion each year (Pimentel 1998).

Nutrient regulation

- United States: biological nitrogen fixation is worth $8 billion each year (Pimentel 1998).
- Globally: biological nitrogen fixation in croplands is worth $20 billion annually (Pimentel et al. 1980 via de Groot 1992).

Waste treatment

- Minnesota: the annual willingness to pay per household for reducing mercury deposition was $118.91, for a total of $212 million statewide (Hagen et al. 1999).
- Chicago, Illinois: in one year, trees removed air pollutants providing $9 million in air quality (McPherson et al. 1997 via Bolund and Hunhammar 1999).

- Massachusetts: waste treatment provided by marshes is worth $123,000 per hectare per year; phosphorus recycling is worth $47,000 per hectare per year (replacement cost) (Oldfield 1984 via de Groot 1992).
- United States: Conservation Reserve Program land can provide $51.1 million per year in air quality benefits through avoidance cleaning and health care costs (Ribaudo et al. 1990 via Feather et al. 1999).
- United States: the value of organismal decomposition of human, animal, and crop waste is $62 billion per year (Pimentel 1998).
- United States: the value of bioremediation of chemical wastes is $23 billion per year (Pimentel 1998).

Pollination

- United States: 90 crops worth $4 billion depend on insect pollination (Pimentel et al. 1980 via de Groot 1992).
- United States: native pollinators (not including honey bees) provide services worth $4.1 to 6.7 billion per year. (Nabhan and Buchmann 1997).

Biological control

- California: biological control projects from 1928-1979 saved $987 million in crop loss and pesticide use (de Groot 1992).
- United States: natural enemies of cotton crop pests prevent crop loss of $191 million annually (Pimentel et al. 1980 via de Groot 1992).
- United States: the benefit of natural enemies is $12 billion (Pimentel 1998).
- Sweden: the average increase for inorganic and organic farmers due to presence of natural predators of an aphid species is $33 per hectare (Östman, Ekbom, Bengtsson 2003).
- Global: the annual cost to replace natural pest control is $54 billion (Naylor and Ehrlich 1997).

<u>Habitat functions</u>

Refugium function

- California: protection of desert habitat is worth $101 per household per year (Richer 1995 via Nunes and van den Bergh 2001).
- New Jersey: protection of beach ecosystems is worth $9.26-15.10 per household per year (Silberman et al. 1992 via Nunes and van den Bergh 2001).
- Colorado: the protection of wilderness areas is worth $32 per household per year (Walsh et al. 1984 via Nunes and van den Bergh 2001).
- Tillamook Bay, Oregon: groups were willing to have society pay $3000-$5000 for each additional acre of protected salmon habitat (group deliberation) (Gregory and Wellman 2001 via Wilson and Howarth 2002).

Nursery function

- United States: coastal marshes, which support offshore fishing, are worth $5,000 per hectare per year (Oldfield 1984 via de Groot 1992).
- United States: the destruction of coastal estuaries between 1954 and 1978 cost $200 million annually in lost fishing revenues (McNeely 1988 via de Groot 1992).

<u>Production functions</u>

Food

- England: wild hops used in breweries provided $15 million in benefits in 1981 (Myers 1983 via de Groot 1992).

Genetic resources

- Yellowstone National Park: Diversa paid $175,000 in 1998 for the rights to research heat-resistant microorganisms in Yellowstone hot springs (Nunes and van den Bergh 2001).
- United States: the value of genetically improved agricultural seed is $1 billion per year; the value of genetically improved animal stock is $500 million per year (Oldfield 1984 via de Groot 1992).
- Costa Rica: in 1991 Merck paid $1 million to INBio in Costa Rica, with royalty agreements, for 2000 samples of genetic material (Nunes and van den Bergh 2001).
- Brazil: Glaxo Wellcome paid $3.2 million to Extracta to screen compounds from 30,000 plant, fungus, and bacteria samples (Nunes and van den Bergh 2001).

Medicinal resources:

- Minnesota: Ginseng in can sell for $225-300 per pound (Tester 1995)
- United States: the economic benefit of plant-derived anti-cancer drugs is $370 billion annually (1990 dollars) (Myers 1997b).
- United States: plant-based drugs and medicines have a market value of $36 billion each year (Pimentel 1998).
- Global: the market value of plant-based drugs was about $43 billion in 1985 in member countries of the Organization for Economic Cooperation and Development (OECD); when social benefits of wages not lost and healthcare costs avoided are included the value increases to $200 billion-$1.8 trillion (Principe 1988 via de Groot 1992).

<u>Information functions</u>

Aesthetic information

- Ramsey County, MN: the implicit price paid for a 10-m increase in house proximity to different wetland types: $101 open water, $148 scrub-shrub, $139 emergent vegetation, $148 forested. (1997 dollars, hedonic pricing method) (Doss and Taff 1996 via Wilson and Carpenter 1999).
- Ramsey County, MN: lakeside properties sell for $41,000 more than non-lakeside properties; each residents is willing to pay $42.66 for a one-acre increase in wetlands in their section of the county, for a total of $6.7 million for all sections (Lupi et al. 1991).
- Lake Bemidji, MN: willingness to pay for water quality improvements is $88 per household (1997 dollars, contingent valuation method) (Henry et al. 1988 via Wilson and Carpenter 1999).
- Minneosta (53 lakes): the implicit price paid for shoreline lots per unit increase in water clarity was $235 (1997 dollars, hedonic pricing method) (Steinnes 1992 via Wilson and Carpenter (1999).
- Pennsylvania: the increase in mean sales of rural property per one-unit increase in pH was $1439 (1997 dollars, hedonic pricing) (Epp and Al-Ani 1979 via Wilson and Carpenter 1999).
- Texas, Lakes Travis and Austin: the implicit prices paid for increasing housing proximity to a lake; waterfront $201, 300 ft $127, and 1500 ft $117 (1997 dollars, hedonic pricing) (Lansford and Jones 1995 via Wilson and Carpenter 1999).
- Amherst, MA: trees add $2686 or 6% to house values (Morales 1980 via Garrod and Willis 1993).
- Athens, GA: landscaping with trees increases sale prices by 3.5 to 4.5%, with an average

increase of $1475 to $1750. This provides an increase of $100,000 per year in city's property tax revenues (hedonic pricing) (Anderson and Cordell 1988 via Garrod and Willis 1993).

- Massachusetts: the household willingness to pay to avoid low-density development on agricultural land was $28-60 annually; to avoid high-density development was $70-176 annually (contingent valuation method) (Halstead 1984).

Recreation

- Minnesota: recreation in the Minnesota Valley National Wildlife Refuge is worth $28.71 per individual per trip (Mathews et al. 1999)
- Pike Lake, WI: trips to the lake are worth $85,721 per year with good water quality (1997 dollars, travel cost method) (Bouwes and Schneider 1979 via Wilson and Carpenter 1999).
- Okoboji, Iowa, East and West Lakes: the value per square foot of property associated with an increase in water quality from boating and fishing to swimming and drinking is $11/ft^2 (1997 dollars, contingent valuation method) (D'Arge and Shogren 1989 via Wilson and Carpenter 1999).
- Northeast and Great Lakes (including Wisconsin, Illinois, and Michigan): recreation values are $9.85 per day for motorboating and waterskiing, $13.90 per day for sightseeing and pleasure driving, and $4.31 per day for big game hunting (Bhat et al. 1998).
- South and North Carolina: river rafting on Chatooga River is $292 per visit, on the Nantahala River is $195 per visit (1997 dollars) (Bowker et al. 1996 via Wilson and Carpenter 1999).
- Columbia River Basin: increased water levels for recreation are worth $16-$125 per indvidual per month (1997 dollars, travel cost method) (Cameron et al. 1996 via Wilson and Carpenter 1999).
- Monangahela River in Pennsylvania; recreation values are $6 per trip to keep water quality boatable, $13 per trip to improve to fishable, and $51 per trip to improve to swimmable (1997 dollars, travel cost method) (Smith and Desvouges 1986 and Smith et al. 1986 via Wilson and Carpenter 1999).
- United States: Conservation Reserve Program land provides $443.8 million per year in small-game hunting benefits (Young and Osborn 1990 via Feather et al. 1999), $175.2 million per year in waterfowl hunting benefits (John 1993 via Feather et al. 1999), $347 million per year in wildlife viewing benefits (Feather et al. 1999) and $80 million per year in pheasant hunting benefits (Feather et al. 1999).

Spiritual and historic information

- Wisconsin: prevention of striped shiner extinction is worth $12 million annually to WI taxpayers (contingent valuation method) (Boyle and Bishop 1987 via Bishop and Welsh 1993).
- California: the mean annual willingness to pay for increases in gray whale populations: for a 50% increase: $25 for visitors, $16.18 for households, for a 100% increase: $29.73 for visitors, $18.14 for households (contingent valuation method) (Loomis and Larson 1994).
- United States: the preservation of the bald eagle is valued at $25 per household per year (Loomis and Helfand 1993 via Nunes and van den Bergh 2001).

ISSUES AND LIMITATIONS

Economic valuation of ecosystem services is an evolving discipline. Both the data needed and methods used have shortcomings. Also, some common economic theories and practices do not apply to ecosystem valuation as well as traditional valuations. Finally, there is a conceptual controversy about the use of ecosystem values.

Valuation of ecosystem services depends on a good understanding of those services, but it is very difficult to know what ecosystem aspects and functions are required to maintain services and to predict how provision of services will change due to human activities (Bingham et al. 1995). This lack of information often causes values to be underestimated (Daily 1997b). The better our ecological knowledge and understanding, the better our valuations will be.

As was mentioned in the ecosystem services section, services interact with and depend on each other. Classifications are arbitrary and useful for discussion, but in reality these services are not independent and could not operate alone. This means that finding a total value of all services in an area is not as simple as valuing each category and adding them up (Daily 1997b). Valuation must be performed carefully to avoid double counting. Use of one service may preclude a different service, such as using wetlands for wastewater treatment limiting recreational uses, while some key services are essential to others (Turner et al. 1998).

Another limitation of ecosystem service valuation is geographical and temporal specificity. The same type of ecosystem could have very different values in different locations due to differences in economic activities, cultures, and lifestyles of the local people. Values also depend on current market prices and preferences, both of which can change over time. Future generations may value a particular service differently than the current one. The geographical and temporal specificity of any service valuation limits extrapolation of current, local values beyond local or bioregional scales and for all times (Daily 1997b, Turner et al. 1998).

Use of market values when possible may seem the best route, but there are problems with this method. Values that incorporate market prices may still be misleading, because many prices do not incorporate subsidies or externalities (the social cost of pesticide pollution, for example), thus underestimating the ecosystem services that support those products (Daily 1997b). Market prices only reflect the cost of using a product and do not take into account the free production of nature. Also, there are many different markets that may place different values on the same thing. Furthermore, markets do not deal with issues of distribution and equity (De Groot 1992).

There are also questions regarding the use of stated preference methods and willingness to pay measures. Willingness to pay depends on the ability to pay, so based on that measurement it will appear that those with a lower income have less value for economic services (Bakker and Matsuno 2001). Another argument against stated preference methods is that preferences do not drive behavior or imply well-being. Some think it is better to base decisions on actual behavior, such as voting. However, some studies have shown that contingent valuation results are similar to those from other methods. Contingent valuation is by no means perfect, but when designed well is useful for revealing values that cannot be found through other methods (Toman 1997).

Even if these values are useful, some do not think that they provide enough information to decision makers. Aggregating individual willingness to pay values is not enough when decisions involve large-scale consequences to society and future generations. These arguments are valid, and it is important to recognize both the current and future dependence on ecosystem services. Still others feel that economic methods do not adequately relay the importance of ecological conditions. They prefer energy-based measurements, where they trace the direct and indirect energy requirement of ecological functions. However, this approach fails to reveal how those functions are valued and connected to human well-being, which is an important part of resource decisions (Toman 1997).

One economic issue is the determination of marginal values. Marginal value is the value of an increment of something, as opposed to the total value of the entire thing, such as the value of 10 hectares of forest out a total 100 hectares. We could not live without ecosystem services, so the total value of all services would be infinite. Likewise, resource decisions do not usually pertain to destroying an entire ecosystem at once (although sometimes they may, such as draining a wetland). What is most relevant is the value of a unit of intact habitat that might be destroyed. As the habitat get smaller, the value of the next remaining units will increase. Ideally, if we can accurately determine the value of each unit, conversion would only occur if the benefits of the economic use are greater than the cost of losing the services of that unit. However, ecosystem services are not provided by certain parts, but by the entire ecosystem. The question is how much those services would be disrupted by losing more area, which is very difficult, if not impossible, to determine (Daily 1997b).

Another economic theory issue is the use of discounted rates. Discounting is the idea that an individual, with an uncertain future and a limited life span, will choose to have something today instead of in the future. This means that the value of something that could be had now is less in the future. The rate used for environmental functions is usually 5-6%, but the standard economic discount is 10% or more. Discounting is a standard practice in economic analyses to determine the present worth of future benefits, but can be problematic with environmental issues. Many feel that ecosystem services, if used sustainably, can last perpetually and should not be valued in the same way as man-made products that quickly lose value. Discounting ecosystem services does not consider future generations and may jeopardize the provision of a crucial resource in the future. Also, ecosystems should not be discounted like man-made products because products can be replaced, while ecosystems generally cannot (de Groot 1992, Gowdy 2001).

The final, and perhaps most fundamental, issue with economic valuation of ecosystem services is: should we be doing it at all? Many feel that we are "generating prices for the priceless and quantifying the unquantifiable" and that we are using money as a common standard to compare things that cannot be compared (de Groot 1992 p. 140). Many feel economic valuation puts conservation on a "slick terrain" because it "provides a rationale for valuing biodiversity but its value is always relative to the values attached to other things" (Randall 1991 p. 65). Some feel that a rationale for conservation should not include human utility, instrumental arguments, or trade-offs (Randal 1991). These are emotional objections, based on ethical arguments that the environment has intrinsic value and is priceless. An alternate emotional objection is that we have a right to ecosystem services and they should be free (de Groot 1992).

There are also more practical objections. Monetary valuation is difficult, if not impossible, to apply to aesthetic or spiritual services. Therefore, many hold that there should be room in decision-making for "priceless experiences" without monetary valuation (de Groot 1992). Also, it is questionable whether economic valuation alone can provide everything needed to make decisions about ecosystem use, management, or preservation and the long-term consequences of those decisions. In some cases, it may be enough, but we must realize that there are many non-monetary values and criteria that are important to consider (Bingham et al. 1995). There is also the question if policy and decision makers will even use these values. Power (2001) points out that political and personal decisions are not usually made with quantified values in mind but by "an informal and thoughtful weighing of costs and benefits" (p. 73).

The emotional objections have a point, but are not very useful when it comes to practical situations. Having a conservation rationale devoid of human utility values would require a broad, overarching societal value for biodiversity that supersedes other political concerns

(Randall 1991). This is not practical or probable. It is easy to say what we need to consistently have environmentally friendly decisions (an intrinsic value basis, etc.), but we obviously are not there yet and it will take a long time for society to change. In the meantime, we must use what tools we have, one of which is economic valuation. It would be useful if decisions took into account "priceless experiences", but what weight would those experiences have compared to other considerations? Economic valuation provides information that can be used to more clearly weigh different factors.

Furthermore, quantifying services may help politicians and financers see the importance and value of services and their conservation. Society is governed by money and numbers, and if we don't put a value on services, they may be ignored in favor of the "quantifiable" (de Groot 1992). Also, valuation provides transparency to decision-making; it is clearer what decisions were based on (Kriström 2001).

Economic valuation of ecosystem services should not be abandoned completely. However, we must be careful to use it in appropriate ways. Most people are not concerned about basic survival, but many environmentalists use the survival of the human species as an argument for conservation. People are concerned, however, about quality of life. It is there that environmental arguments and economic valuations can be most effective (Power 2001). Toman (1997) adds that valuation should not be used unrelated to choices. Ecosystem service valuation can be an important tool for ecosystem policy and management, although valuation becomes more difficult and uncertain as the ecosystem services becomes more complex. It is important to realize that ecosystem service valuation can be a useful too but cannot alone provide all the information needed to solve a problem. These economic arguments are best used along with and to support political and social considerations (Toman 1997).

CONCLUSION

Ecosystems provide a myriad of services that contribute to human survival and quality of life. Though many services overlap and are interdependent, it is useful to attempt to classify them, as was done by de Groot et al. (2002). These services can then be applied to local ecosystems, such as the forests, prairies, and freshwater systems of southeast Minnesota.

Humans value each ecosystem service in one or more ways, including direct use, indirect use, and non-use values. The services and values in turn can be quantified using economic methods, such as direct market pricing, travel cost evaluations, or contingent valuation surveys. Each method has advantages and disadvantages, and should be carefully chosen based on the specific goals and subject of the study. Not only are there issues with individual methods, but there are issues with economic theory and the idea of economically valuing ecosystem services in general.

Despite difficulties, limitations, and issues surrounding ecosystem service valuation, there does seem to be a general consensus that the value of ecosystem services often outweighs economic use and that protecting ecosystem services is, or should be, one of the most important responsibilities of today's politicians, resource managers, and society in general (Balmford et al. 2002; Daily 1997b; Salzman, Thompson, and Daily 2001)

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APPENDIX

Acres of native communities in southeastern Minnesota counties. *Acreages for specific Goodhue County communities were not given. Sources: Dunevwitz 1993; MCBS 1994b, 1996a,b 1997a,b,c.

Community Type	Goodhue*	Wabasha	Olmsted	Winona	Fillmore	Houston	Total*
DECIDUOUS FOREST							
oak forest	x	3360	4490	16120	10710	16440	51120
maple-basswood forest	x	1600	1240	2470	2170	1080	8560
lowland hardwood forest	x	160	570	830	1400	410	3370
CONIFEROUS FOREST							
upland white cedar forest				30			30
MIXED CONIFEROUS-DECIDUOUS FOREST							
white pine-hardwood forest	x	240	160	490	430	130	1450
northern hardwood-conifer forest				10	20		30
DECIDUOUS WOODLAND							
oak woodland-brushland	x	200	960	2390	460	750	4760
DECIDUOUS SAVANNA							
mesic oak savanna					20		20
dry oak savanna	x	340	10	860	80	380	1670
CONIFEROUS SAVANNA							
jack pine barrens				90	10		100
UPLAND PRAIRIE							
mesic prairie	x	30		200	90		320
dry prairie	x	1320	210	2130	430	1970	6060
FLOODPLAIN FOREST	x	3210	1040	4160	250	6340	15000
HARDWOOD SWAMP FOREST							
black ash swamp				<10	20	<10	40
mixed hardwood swamp		10		50			60
SHRUB SWAMP		130	70			220	420
willow swamp	x						
EMERGENT MARSH	x						
cattail marsh						20	20
mixed emergent marsh		360		690		2970	4020
WET MEADOW/ FEN							
wet prairie			40		10		50
calcareous seepage fen	x		30	10	20		60
wet meadow			140		110	70	320
seepage meadow		10		610	30	60	710
meadow-marsh-swamp complex		1450					1450
PRIMARY COMMUNITY							
moist cliff	x	20	30	50	420	60	580
dry cliff	x	50	20	120	1290	110	1590
talus slope		5	30	20	70	40	165
river beach					30	100	130
Total acres of native communities	33000	12495	9040	31340	18070	31160	135105
Percent of acres in county	7%	3.70%	2.20%	7.85%	3.30%	8.80%	32.84%

Special concern, threatened, and endangered species present in southeastern Minnesota counties.
* indicates that the species has not been documented since 1970.
SC=Special concern, T=Threatened, E=Endangered. Federal status is given where applicable (Fed. E= Federally endangered).
Sources: Dunevwitz 1993; MCBS 1994a,b,c 1996a,b 1997a,b,c; MN-DNR 1996.

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
PLANTS								
Adoxa moschatellina	moschatel	SC	x	x	x	x	x	x
Agalinis gattingeri	round-stemmed false foxglove	E		x*		x*		
Allium cernuum	nodding wild onion	T			x	x	x	
Aristida tuberculosa	sea-beach needlegrass	SC		x		x	x	x
Arnoglossum plantagineum	tuberous Indian-plantain	T	x*		x		x	x
Asclepias amplexicaulis	clasping milkweed	SC		x		x	x	x
Asclepias hirtella	prairie milkweed	T						x
Asclepias stenophylla	narrow-leaved milkweed	E						x
Asclepias sullivantii	Sullivant's milkweed	T					x	
Asplenium platyneuron	ebony spleenwort	SC		x		x	x	x
Aster shortii	Short's aster	T				x*	x	x
Aureolaria pedicularia	fernleaf false foxglove	T				x		
Baptisia alba	white wild indigo	SC		x	x		x	x
Baptisia bracteata var. leucophaea	plains wild indigo	SC		x	x	x	x	x
Bartonia virginica	virginia bartonia	E	x					
Besseya bullii	kitten-tails	T	x	x				
Botrychium campestre	prairie moonwort	SC				x		
Bryoxiphium norvegicum	sword moss	SC				x		
Cacalia suaveolens	sweet-smelling Indian-	E		x	x		x	x

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
	plantain							
Carex annectens	yellow-fruited sedge	SC		x			x	
Carex careyana	Carey's sedge	T		x		x	x	x
Carex crus-corvi	raven's foot sedge	SC		x*				
Carex davisii	Davis' sedge	T		x				x
Carex formosa	handsome sedge	E			x			
Carex jamesii	James' sedge	T		x	x		x	x
Carex laevivaginata	smooth-sheathed sedge	T		x		x	x	x
Carex laxiculmis	spreading sedge	T		x	x	x	x	x
Carex plantaginea	plaintain-leaved sedge	E		x		x		
Carex sterilis	sterile sedge	T	x		x	x		
Carex typhina	cattail sedge	SC		x		x		x
Carex woodii	wood's sedge	SC			x	x	x	x
Cheilanthes lanosa	hairy lip-fern	E				x		
Chrysosplenium iowense	Iowa golden saxifrage	E					x	x
Cirsium hillii	Hill's thistle	SC	x	x	x	x	x	x
Cypripedium candidum	small white lady's slipper	SC				x	x	x
Desmodium cuspidatum var. longifolium	big tick-trefoil	SC						x
Desmodium nudiflorum	stemless tick-trefoil	SC		x		x	x	x
Diarrhena obovata	American beakgrain	SC					x	
Dicentra canadensis	squirrel-corn	SC	x	x	x	x	x	x
Diplazium pycnocarpon	narrow-leaved spleenwort	T		x	x	x	x	x
Dodecatheon meadia	prairie shooting star	E						x
Draba arabisans	rock whitlow-grass	SC			x		x	

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
Dryopteris goldiana	Goldie's fern	SC		x	x	x	x	x
Dryopteris marginalis	Marginal shield-fern	T						x
Eryngium yuccifolium	rattlesnake-master	SC	x	x*	x	x	x	x
Erythronium propullans	dwarf trout lily	E, Fed. E	x					
Eupatorium sessilifolium	upland boneset	T				x*		x
Floerkea proserpinacoides	false mermaid	T		x	x	x	x	
Hamamelis virginiana	witch-hazel	SC				x	x	x
Hudsonia tomentosa	beach-heather	SC		x				
Huperzia porophila	rock clubmoss	T				x		x
Hydrastis canadensis	Golden-seal	E			x	x	x	
Hydrocotyle americana	American water-pennywort	SC						x*
Iodanthus pinnatifidus	purple rocket	E					x	
Jeffersonia diphylla	twinleaf	SC	x	x	x	x	x	x
Juglans cinerea	butternut	SC		x	x	x	x	x
Juniperus horizontalis	creeping juniper	SC				x		x
Lechea tenuifolia	narrow-leaved pinweed	E					x	
Leersia lenticularis	catchfly grass	SC		x		x		x
Lespedeza leptostachya	prairie bush clover	T, Fed T	x		x			
Lesquerella ludoviciana	bladder pod	E	x					
Melica nitens	three-flowered melic	T					x	x
Minuartia dawsonensis	rock sandwort	SC	x	x			x	x*
Montia chamissoi	montia	E				x		
Napaea dioica	glade mallow		x	x	x		x	x*
Oenothera rhombipetala	rhombic-petaled evening primrose	SC		x				x

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
Orobanche fasciculata	clustered broomrape	SC		x		x*	x	
Orobanche ludoviciana	Louisiana broomrape	SC				x*		
Orobanche uniflora	one-flowered broomrape	SC		x		x	x	x*
Panax quinquefolius	American ginseng	SC	x	x	x	x	x	x
Paronychia canadensis	Canadian forked chickweed	T					x	x
Paronychia fastigiata	forked chickweed	E				x*		
Parthenium integrifolium	wild quinine	E					x	x*
Pellaea atropurpurea	purple cliff-brake	SC		x		x	x	x
Phegopteris hexagonoptera	broad beech-fern	T		x		x	x	x*
Platanthera flava var. herbiola	tubercled rein-orchid	E	x	x*				
Platanthera praeclara	western prairie fringed orchid	E, Fed T					x*	x*
Poa paludigena	bog bluegrass	T						x
Poa wolfii	wolf's bluegrass	SC			x	x	x	x
Polygala cruciata var. aquilonia	cross-leaved milkwort	E				x*		
Polystichum acrostichoides	Christmas fern	T				x		x
Polytaenia nuttallii	Prairie-parsley	SC					x*	
Psoralidium tenuiflora	slender-leaved scurf pea	E					x	x
Prenanthes crepidinea	nodding rattlesnake root	SC						x*
Rhynchospora capillacea	hair-like beak-rush	T			x	x*		
Rudbeckia triloba	three-leaved coneflower	SC			x*			x
Sanicula trifoliata	beaked snakeroot	SC	x			x	x	x
Sclera verticillata	whorled nut-rush	T			x			
Scutellaria ovata	ovate-leaved	T	x	x		x		x

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
	skullcap							
Sedum integrifolium ssp. leedyi	Leedy's roseroot	E, Fed T			x		x	
Silene nivea	snowy campion	T				x	x	x
Solidago sciaphila	cliff goldenrod	SC		x	x	x	x	x
Sullivantia sullivantii	reniform sullivantia	T				x	x	x
Symphoricarpos orbiculatus	coralberry	SC						x
Talinum rugospermum	rough-seeded fameflower	E		x		x	x	x
Tephrosia virginiana	goat's rue	SC		x		x	x	x
Trillium nivale	snow trillium	SC	x	x	x	x	x	
Triplasis purpurea	purple sand-grass	SC		x				x
Valeriana edulis ssp. ciliata	valerian	T	x	x	x	x	x	x
Verbena simplex	narrow-leaved vervain	SC					x*	x*
Viola lanceolata	lance-leaved violet	T				x*		
Vitis aestivalis	silverleaf grape	SC		x*		x		x
MAMMALS								
Cryptotis parva	least shrew	SC				x*		
Microtus ochrogaster	prairie vole	SC	x			x	x*	x
Microtus pinetorum	woodland vole	SC				x		x
Myotis septentrionalis	northern myotis	SC	x			x	x	x
Perognathus flavescens	plains pocket mouse	SC	x	x				
Pipistrellus subflavus	eastern pipistrelle	SC	x	x*		x	x	x
Spilogale putorius	eastern spotted skunk	T		x*	x*	x*	x*	x*
BIRDS								
Ammodramus henslowii	Henslow's sparrow	E		x*		x	x	
Buteo lineatus	red-shouldered hawk	SC	x	x		x	x	x

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
Dendroica cerulea	cerulean warbler	SC		x	x	x	x	x
Empidonax virescens	Acadian flycatcher	SC	x	x	x	x	x	x
Falco peregrinus	peregrine falcon	T, Fed E	x*	x	x	x		x*
Gallinula chloropus	common moorhen	SC		x		x		x
Haliaeetus leucocephalus	bald eagle	SC, Fed T	x	x	x	x	x	x
Lanius ludovicianus	loggerhead shrike	T	x	x	x	x	x	
Rallus elegans	king rail	E						x
Seiurus motacilla	Louisiana waterthrush	SC		x	x	x	x	x
AMPHIBIANS AND REPTILES								
Acris crepitans	northern cricket frog	E			x*		x*	x
Apalone mutica	smooth softshell	SC		x	x	x		x
Chelydra serpentina	snapping turtle	SC				x		x
Clemmys insculpta	wood turtle	T	x	x	x			
Coluber constrictor	racer	SC	x	x	x	x	x	x
Crotalus horridus	timber rattlesnake	T	x	x	x	x	x	x
Elaphe obsoleta	rat snake	SC			x*			x
Emydoidea blandingii	Blanding's turtle	T	x	x	x	x	x	x
Eumeces fasciatus	five-lined skink	SC					x	x
Heterodon nasicus	western hognose snake	SC		x				
Pituophis catenifer	gopher snake	SC	x	x		x	x	x
Sistrurus catenatus	massasauga	T		x*				x
FISHES								
Acipenser fulvescens	lake sturgeon	SC		x		x		x
Ammocrypta asprella	crystal darter	SC		x		x		
Cycleptus elongatus	blue sucker	SC		x		x		x
Erimystax x-punctata	gravel chub	SC					x	x
Ichthyomyzon	northern	SC			x			

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
fossor	brook lamprey							
Morone mississippiensis	yellow bass	SC		x		x		x
Notropis amnis	pallid shiner	SC		x*		x*		x
Notropis nubilus	ozark minnow	SC			x		x	
Polyodon spathula	paddlefish	T		x		x		x
MUSSELS								
Actinonaias ligamentina	mucket	T	x	x	x	x		
Arcidens confragosus	rock pocketbook	E				x		x
Cyclonaias tuberculata	purple wartyback	T		x				
Ellipsaria lineolata	butterfly	T				x		x
Lampsilis higginsi	Higgins eye	E, Fed E				x		x
Lampsilis teres	yellow sandshell	E	x					
Lasmigona costata	fluted-shell	SC		x	x			
Ligumia recta	black sandshell	SC		x		x		x
Novasuccinea n. sp. minnesota a	Minnesota pleistocene ambersnail	T			x		x	
Novasuccinea n. sp. minnesota b	Iowa pleistocene ambersnail	E			x		x	
Plethobasus cyphyus	sheepnose	E		x				
Pleurobema coccineum	round pigtoe	T		x				
Quadrula metanevra	monkeyface	T		x		x		x
Quadrula nodulata	wartyback	E				x		
Vertigo hubrichti hubrichti	Midwest pleistocene vertigo	E					x	x
Vertigo hubrichti variabilis n. subsp.	variable pleistocene vertigo	T					x	
Vertigo meramecensis	bluff vertigo	T		x	x	x		
BUTTERFLIES								
Hesperia ottoe	ottoe skipper	T		x		x		x

Scientific name	Common name	MN Status	Goodhue	Wabasha	Olmsted	Winona	Fillmore	Houston
Lycaeides melissa samuelis	Karner blue	E, Fed E				x		
SPIDERS								
Phidippus apacheanus	jumping spider spp.	SC		x				
Total number of rare species			37	83	55	97	83	104