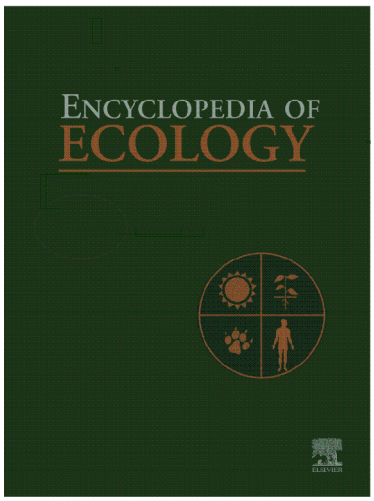

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other basic environmental resources. An ecological engineering approach can help encourage the development of sustainable ecosystems and assist human society in making better use of our natural resources. There is a critical need to alert the public worldwide to the serious issues of overpopulation and natural resource shortages.

Certainly populations in developed countries could contribute to the conservation effort by reducing their high consumption of all resources, especially fossil fuels. Focus is needed on improving food crops, such as developing perennial grains, pest-resistant crops, and improved nutritional makeup of crops.

Sustainability for future generations will not be insured until the rate of population growth is substantially reduced and resources essential for maintaining human life and environmental integrity are conserved.

See also: Agriculture Systems; Erosion; Organic Farming; Sustainable Development; Water Availability.

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Hunting

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Introduction

Hunting is the practice of pursuing, capturing, or killing wildlife. This broad definition can be divided into subsistence, commercial, and recreational hunting. Subsistence hunting provided the primary source of protein for most humans prior to widespread domestication of animals and evolution of agricultural societies (2 500 000–10 000 BCE). When agriculture and animal husbandry emerged (10 000 BCE), hunting began moving from a subsistence practice to a cultural practice. This transition is largely complete in developed nations where hunting is an insignificant source of protein. Subsistence hunting, however, still persists in economically depressed areas (e.g., much of rural Africa), and in relatively isolated cultural groups (e.g., Arctic Inuit).

In areas where survival was not the primary objective of hunting, the practice evolved into extermination, commercial, and recreational varieties. Extermination hunting involves attempts to eliminate wildlife which prey on or compete with domestic livestock or crops or threaten human safety. Commercial hunting for meat, hides,

plumage, or other tissues (e.g., tusks, antlers, horns, claws, and skulls) often involves special training and utilizes efficient, rather than traditional or stylized, weapons. Recreational hunting evolved as a luxury sport of higher social classes in early agricultural societies (e.g., ancient Egypt and Mesopotamia). In Europe, sport hunting remained in the realm of royalty or aristocracy through the colonial period, and that tradition spread to some colonies (e.g., India). Social and ecological contexts in colonial North America, however, led to a modern hunting culture without strong ties to social class. While modern recreational hunting is often associated with sport hunting (e.g., trophy hunting), many hunters participate primarily to experience the outdoors and associate with other hunters. This hunting culture plays a major role in advertising, economics, and social practices in many rural areas throughout the world. Formal 'cultural hunting' regulations also recognize the central role of hunting for some tribal groups.

In the United States, self-sufficient and conservation-minded sportsmen hunters embodied by Theodore Roosevelt represented a shared view of hunting prior to the 1960s. The civil and women's rights movements, Vietnam War and the peace movement, and environmental movement, however, led to a more critical public in late 1960s and early 1970s. Since then, animal welfare and animal rights groups have successfully lobbied against several forms of sport hunting (e.g., 'canned' hunts of penned wildlife, hound hunting of fox and bear) and commercial whaling. These successes combined with steady decline in hunter recruitment, retention, and numbers during the same period suggest future changes in hunting culture and practice.

Ecological Effects of Hunting

The ecological effects of hunting are no less diverse than its history. While hunters act as apex predators in ecological terms, human hunters rarely conform to the assumptions of the Lotka–Volterra equations (predator–prey equations). Human hunters can and often have operated as keystone predators, exerting a disproportionate effect on prey populations relative to human numbers. The ecological effects of modern hunting, however, are mediated by governmental regulations. Throughout much of the twentieth century, the maximum sustainable yield paradigm guided hunting regulations. During the latter half of the twentieth century fixed harvest quotas based on maximum sustainable yield decimated many global fisheries and whale populations. This failure led to regulation of hunting effort (season timing and length, bag limits, means/methods (archery vs. firearms)). Such regulations control harvest indirectly by altering hunting effort and hunter efficiency. Because hunter effort required to bag an animal increases as prey abundance declines, effort-based harvest regulations are less risky than quota-based systems should initial prey populations be overestimated. This allows regulators time to adaptively implement changes designed to decrease take should this be required.

Idealized narratives of indigenous cultures suggest early humans evolved sustainable hunting systems in a delicate balance with local ecosystems. While some indigenous cultures clearly exhibit sustainable hunting practices (e.g., the Amazonian Korubo, Artic Inuit, South African Bushmen), the apparent stability may reflect historic extinctions of most species vulnerable to indigenous hunting techniques. Many indigenous hunters actively manipulated ecosystems to facilitate hunting. Early hunters in every continent transformed ecosystems by setting fires to drive animals into traps, facilitate tracking animals, and create favorable habitat for prey species. The landscapes greeting European colonists in North America and Australia reflected the fires aboriginals used to create habitat for hunted species.

The overkill hypothesis for the Pleistocene megafauna extinction event represents the paradigm case of unsustainable hunting (**Figure 1**). Radiation of hunting cultures into North and South America around 10 000 BCE coincided with extinction of 33 of 45 and 46 of 58 large mammal genera in each continent, respectively. Since 1600, hunting caused 23% of all known animal extinctions. The list of species driven to extinction (e.g., passenger pigeon (*Ectopistes migratorius*), heath hen (*Tympanuchus cupido cupido*)), extirpated from most of

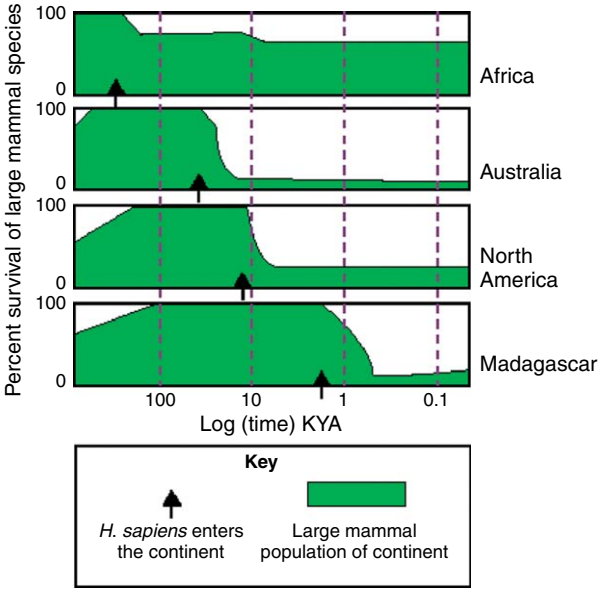

Figure 1 Timeline of large mammal extinctions and entry of humans in Africa, Australia, North America, and Madagascar. Adapted from Martin 1989 by Elin Whitney-Smith.

their range (e.g., bison (*Bos bison*)), or threatened (e.g., most whale species) by commercial hunting is staggering. Such changes wrought by hunting often have ripple effects throughout ecosystems. For instance, as domestic livestock replaced extirpated bison, brown-headed cowbirds (*Molothrus ater*) adopted the sedentary lifestyle of their domestic symbionts and became North America's most notorious avian brood parasite. Recreational hunting has had more mixed ecological impacts. In some contexts (e.g., Medieval and Colonial Europe), hunting motivated preservation of forest ecosystems as game preserves. Aristocratic sport hunting, however, nearly led to extinction of the Bengal tiger (*Panthera tigris tigris*).

Hunting became an almost universally positive ecological force during the conservation movement of the late 1800s and early 1900s (to which prominent hunters including Theodore Roosevelt contributed heavily). In the United States, federal excise taxes on hunter purchases (>$200 million annually) support most state-level wildlife management programs in the United States, and the mandatory purchase of Federal Duck Stamps by migratory waterfowl hunters since 1934 helped purchase more than 20 000 km^2 of wildlife habitat in the National Wildlife Refuge System. Recreational hunters also contributed to restoration of North America's decimated game species including white-tailed deer (*Odocoileus virginianus*), pronghorn (*Antilocapra Americana*), black bear (*Ursus americanus*), wild turkey (*Meleagris gallopavo*), and wood duck (*Aix sponsa*). Hunters also contributed to establishment of wildlife reserves and conservation-hunting programs throughout the world. The conservation–hunting programs epitomized by Zimbabwe's Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) provide locals in developing nations a sustainable supply of money and meat and preserve local wildlife species. Finally, in areas dominated by private land ownership, hunting provides economic incentives for protecting natural and agricultural lands from suburban or commercial developments.

Some ecologically questionable practices, however, have evolved to capitalize on the growing economic value of hunted species, including high fencing, supplemental feeding, and landscape manipulation to support economically valuable species. While these practices may render keeping private lands in a somewhat natural state more economically viable, they are ecologically problematic. High fences effectively fragment landscapes for many species, supplemental feeding increases the risk of disease transmission, and landscape manipulation intended to help commercially valuable wildlife can threaten other species.

Modern hunting also provides an important tool for managing overabundant wildlife species. Hunting allows natural resource managers to control populations of species before they exceed carrying capacity of their habitat, damage vegetation, threaten other species, or threaten human health and safety. Managers also can use hunting to control a wildlife population's density in efforts to minimize risks associated with wildlife-related diseases (e.g., Lyme disease, bovine brucellosis). In 2005, hunting became a major tool to fight degradation of saltwater marshes caused by growing populations of lesser snow geese (*Chen caerulescens caerulescens*) along the Hudson Bay. Some groups assert reintroducing predators would achieve the same benefits as hunting. Such reintroductions, however, prove politically problematic. Further, considerable evidence suggests prey species typically control predator abundance rather than vice versa.

Ecological Effects on Hunting

Because successful hunting requires a clear understanding of the relationship between the prey species and its biotic and abiotic environment, hunters were probably the first ecologists. In early human history, hunting made most people ecologists by necessity. Now millions of recreational ecologists study the relationships between wildlife and their environments with hopes of increasing the likelihood of successful hunts. Because hunters were among the first ecologists, and continue to study relationships among game species, other organisms, and the abiotic environment, ecosystems shaped and shape the practice of hunting. Hunting generally occurs in areas where prey species predictably occur. Like nonhuman predators, hunters have always focused their efforts in areas and at times where prey species meet critical needs (e.g., food, cover, rest, reproduction). In arctic areas hunters target seals at breathing holes in ice, in arid areas hunters wait near watering holes, and salt and other mineral deposits (natural and artificial) provide a common hunting location throughout the world. Deer hunters often position themselves between cover and foraging areas during dawn and dusk when deer predictably move between these areas. Waterfowl hunters position themselves on or near small water bodies where waterfowl rest along migration routes during fall migrations.

Biodiversity also influenced the persistence of subsistence hunting. In areas lacking domesticatable species, hunting remained essential to human survival until domestic plants and animals were imported from other areas. Changing landscape patterns have also influenced hunting. As agriculture and urban sprawl created a fragmented landscape in many areas, popular game species – including white-tailed deer and Canada geese (*Branta canadensis*) – became nuisances in suburban areas. In many such cases, hunting in nearby areas became an important tool for controlling those nuisance species.

While technology (e.g., firearms, motor vehicles) has allowed modern hunting to develop independent of

ecological relationships in some ways, ecosystems have shaped the social nature of hunting. In relatively open landscapes, persistence hunting (using teamwork to run down prey) evolved. In densely forested areas, hunting evolved to be less of a group activity. Attributes of prey also influenced the social nature of hunting. Large prey species required larger groups of hunters, processors, and eaters. Even with modern technology, however, ecosystems influence the social dynamics of hunting. Emerging zoonotic diseases are shaping perceptions of hunting risk and influencing hunting participation. When chronic wasting disease (CWD) was discovered in Wisconsin (USA) deer herds in 2002, hunter numbers began declining and more than 50% of deer hunters using firearms that hunted in 2001, but not 2002, cited CWD as their reason for not hunting.

See also: Biodiversity.

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Hydrodynamic Models

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Introduction

The use of computers to simulate ocean currents, sea level, and the distribution of marine properties has come into its own in the past 15 years. The field of hydrodynamic modeling now includes a variety of approaches that are commonly employed in three-dimensional, Eulerian, open-ocean, and coastal modeling studies. The rapid evolution of computing has driven growth of the field of hydrodynamic modeling, which has been catalyzed by the sharing of most models as opensource software (i.e., those that are freely available for general scientific use, as opposed to codes that are proprietary or with restricted source code availability). While the basic equations which underlie numerical hydrodynamic models are universally known, there are a wide variety of methods used to solve the systems. These affect the structure of the discrete grids used for the computations. The models can be classified by their grid methods: regular or irregular horizontal grids, and a variety of vertical discretization schemes. Models also differ through the approximations which are required to model irresolvable processes, such as turbulent motions and complex interactions with the atmosphere. A wide variety of modeling techniques are required to satisfy the diverse modeling applications, from shallow water estuaries and open-ocean circulation to integrated earth system modeling used for global climate studies.

History of Ocean Modeling

Models depicting the circulation and properties of the global oceans were developed in response to the maturation of the field of meteorological modeling. The first ocean models were constructed by Kirk Bryan and implemented