UNIT 1

CIVILIZATION AND NATURAL SYSTEMS: THE ROLE OF RESOURCES THROUGHOUT HUMAN HISTORY

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1. Introduction

The early 21st century is a time of both challenge and opportunity for the world’s engineers. With global population continuing to rise and standards of living improving rapidly in many countries, there has never been such demand on the earth’s resources. Using these resources in a way that best benefits humankind, now and in the future, is a major tenet of the emerging discipline of Sustainable Engineering.

The 1987 groundbreaking report *Our Common Future* (1) noted that attitudes in many of the world’s most advanced countries were expressed by satisfaction, essentially “life is good and we hope the rest of the world catches up to us.” There was little recognition that the “good life” requires using the earth’s resources at rates much greater than those found in developing countries. Furthermore, there was little concern about our lack of knowledge of those resources: their quantity, the form they are in, their locations, and the technical and political realities of getting access to them. There was also little concern about the distribution of resources to enable more if not all of the world’s people to enjoy the good life, and the implications of a more equitable distribution of resources on lifestyles in the richest nations of the world.

As engineers, we have traditionally done what we are asked to do by decision makers, those in charge of companies, governments, and other organizations. Such decision makers rely on a constituency to achieve power and hold onto it; rarely are poor and destitute people a key part of this constituency. So perhaps it is only natural that engineers have been tasked primarily with improving lifestyles of the already-comfortable. Thus the gap has grown. Simultaneous with this realization, we note that achieving sustainability with our limited resources requires saving some of those resources for future times. There is no way we can ask people to save for the future if their survival today depends on getting enough resources, i.e., food, water, and shelter. Thus abject poverty cannot be part of the solution.

We are now facing a new dilemma: the population of the poor and the population of the already-comfortable are both so large that there is a question of whether we have the resources, let alone the political will, to improve lifestyles of the former while maintaining those of the latter. Tackling this problem requires making far better use of the earth’s resources, and that is a responsibility of engineers.
These challenges are enormous, but humankind has faced enormous challenges before. Some have been met with success and some with failure. The challenge of sustainability is a tremendous opportunity for engineers to take a stand and make a difference to the course of civilization.

Environmental historians have noted that history is replete with examples of the relationship between human well-being and the earth’s resources. The very success or failure of civilizations has depended on the state of those resources at the time and place of each civilization. Thus even though humans have never before experienced global problems like loss of biodiversity, stratospheric ozone depletion, and global climate change, we nevertheless can look at losses on a local scale throughout history to learn about the possible impacts of our current actions. And since we are dealing with resource losses on a global rather than local scale, the stakes are obviously much higher today.

It is important to define the term “resources” in the context of this chapter. Here we mean energy, materials, water, and air as well as the ability of the earth to serve as a sink for wastes of our civilization. This last resource is especially important. Nature has an ability to overcome many of our waste products. For example, water contaminated by human or animal excreta will become purified as it is transported by rivers, streams, or groundwater over a period of time. Other types of contamination in water may take shorter or longer periods of time to become purified, depending on the type of contaminant. If the amount of waste is too great or the contaminant is resistant to degradation, however, the natural purification processes may be overwhelmed, in which case there can be long-term environmental damage.

We begin Chapter 1 with a discussion of resource use throughout history. We briefly mention relevant social issues and political forces as well as environmental attitudes as we review this history to put resource use in context. We then summarize current concepts of sustainability and explore how failures and successes in the past can be used to assist in understanding the current dilemma.

2. Use of the Earth’s Resources by Past Civilizations

2.1. The Stone Age and Bronze Age up to 1500 BCE

Agriculture began prior to 8000 BCE in the late Stone Age. The discovery that seeds of certain crops could be planted and grown reliably, producing food for large numbers of people, transformed civilization from a nomadic, hunter-gatherer society to an urban culture.

2.1.1. Jericho, Anatolia, and Mesopotamia

The world’s oldest known settlement, Jericho, originated sometime before 8000 BCE in what is now the West Bank (2). The town had at least 2,000 inhabitants who lived in houses of mud bricks with their floors well below ground level. The entire town occupied an area of about ten acres, or roughly four hectares. Wild grains, especially wheat, grew in the hills near Jericho and originally provided food for the townspeople. The physical structure of the wheat plants provides information about human use of this grain: the plants that originally grew near Jericho had heads which easily
shatter when the seeds ripen, allowing the seeds to fall to the ground and become the next generation of plants. Due to mutations, some of the plants had heads that did not shatter; archaeological evidence shows that the villagers collected these plants and cultivated them in the land around Jericho, since the wheat from these hardier plants could be more easily harvested. Thus human interference in natural plant cycles by spreading the occurrence of mutated plants is as old as agriculture itself.

Domestication of wheat became widespread and allowed larger communities to develop. The town of Catal Hüyük in Anatolia, modern-day Turkey, had a population of more than 5,000 (2). These people grew grains and domesticated animals including aurochs, which were wild cattle with horns up to two meters long. Perhaps as important as growing and harvesting grains, people in this region developed new methods of storing large amounts of grain and other food out of the reach of animals. This was achieved by making clay pots and other ceramics as early as 6500 BCE (2). The beginning of ceramics ushered in the final period of the Stone Age known as the Neolithic Period.

The Sumerians were among the first people to develop cities (3). They occupied Mesopotamia, which literally means “between the rivers” in Greek, the region between the Tigris and Euphrates Rivers in modern-day Iraq. The inhabitants made extensive use of the earth’s resources. For example, the southern Mesopotamian city of Uruk with 25,000 inhabitants constructed large palaces and temples. They made wooden plows for farming, domesticated oxen to pull their plows, and built networks of canals for irrigation. The land surrounding each city for many kilometers was used for growing wheat, barley, and other grains to support the urban dwellers. In addition, evidence of the earliest written language was found in Uruk: clay tablets containing pictographs, or pictures representing objects, date back to the early fourth millennium BCE (4). Over time the pictographs became simplified to wedge-shaped symbols, known as cuneiform writing (after cuneus, Latin for “wedge”). These tablets are believed to have been intended to keep track of cattle, sheep, grain, and other farm goods.

People in Mesopotamia, Anatolia, and adjacent regions are credited with the first advancements in the art of working with metals, starting with copper as early as 7000 BCE (5). Metalworking began with hammering or otherwise shaping a native metal, then progressed to annealing, or heating the metal in a fire to make it easier to shape, which eventually gave way to casting where the metal is raised to a temperature above its melting point so it becomes a liquid. The discovery of casting may have occurred inadvertently when native copper subjected to annealing reached its melting temperature of 1083°C and melted into the fire (6). This probably occurred sometime in the sixth or fifth millennium BCE (5). Another important discovery occurred when it was found that certain rocks contained metals that could be smelted at a high temperature to separate the pure metal from the ore. Ores containing copper and lead were among the first ones to be smelted around 4000 BCE, as certain ores of both metals have reduction temperatures around 1200 to 1300°C (6, 7). There are debates among metallurgical historians about whether the first smelting could have occurred in a hearth fire or a pottery kiln.

A challenging problem with smelting of copper ore, as well as the ores of lead and other metals, is that certain constituents in the ore form a residue with a high melting point known as “gangue” (8). The process of heating the ore results in pure copper in the form of finely dispersed droplets embedded in the gangue; the droplets are impossible to recover in this form. By adding another
metal oxide such as hematite, which is an oxide of iron, the melting point of the gangue decreases until it melts. The copper droplets then coalesce as the gangue becomes liquid, and since copper is denser than the gangue, it sinks and is collected as pure metal. The metal oxide is known as a “flux,” and the fluxing process was an important discovery at this time.

Yet another major finding was the discovery that alloys which are substances composed of two or more metals can, in some cases, be much stronger than an individual metal. One of the first alloys was probably produced unwittingly when early metallurgists smelted copper ore which naturally contained traces of arsenic. The resultant copper-arsenic alloy is actually an early form of bronze, and it was indeed much stronger than pure copper. This way of obtaining a stronger metal was not reliable, however, since the volatility of arsenic meant that an unpredictable amount of it vaporized during the smelting process (9). The ancients realized the importance of alloys quite early, and they were already experimenting with impurities added to copper by the fourth and third millennia BCE (10). By 3200 BCE, the ancients had developed a more reliable form of bronze, adding tin to copper, and this discovery marked the end of the Stone Age and beginning of the Bronze Age in the Middle East (9). Even with this discovery, copper and copper-arsenic bronze were far more widely used than copper-tin bronze for another one thousand years. Note that the successful development of bronze took place at different times elsewhere in the world, e.g., the Bronze Age in Britain began several hundred years later (11).

By 3000 BCE in Mesopotamia, lead and silver were mined and smelted (6), and copper was smelted and widely used for weapons, vases, mirrors, and tools of agriculture such as hoes and plows (9). The copper industry relied on imports, as there are very few naturally occurring copper ores in the region. Traders brought ores, probably copper oxides and copper carbonates, from Cyprus, Anatolia, and the Negev Desert (7). Because of its expense, metalworkers in Mesopotamia recycled large amounts of copper, keeping imports to a minimum (9). Sometime in the third millennium, the easily smelted oxide and carbonate ores became exhausted (7). This caused smelters to switch to copper sulfide ores from Anatolia which were more difficult to work with, but which were plentiful so that the copper industry grew markedly as technological innovations gained momentum. By 2000 BCE, copper from Anatolia was being mass produced in large quantities for communities thousands of kilometers away (12).

A limiting factor in the smelting of copper in ancient times was the availability of fuelwood. Historians estimate that it took about 20 kg of charcoal to make each kg of copper, and about 7 kg of wood to make each kg of charcoal (7, 13). For the Sumerians, this was a major inconvenience as there is little woodland in the arid regions on Mesopotamia, necessitating transport from distant forests.

Availability of wood was probably a limiting factor in other aspects of urban life in this part of the world. Buildings required wood timbers for roof support and for scaffolding during construction (13). Houses were made of mud brick, some of which were kiln-fired using charcoal made from wood, and had plaster walls and terrazzo floors both of which required kiln firing (14). Giant kilns for making roof tiles, requiring huge amounts of wood for firing, were built (15). In addition, the manufacture of mortar for bricks employed kiln firing, although the Sumerians discovered that bitumen seeping from their vast but unknown oil fields was a better adhesive for their construction (16). All of this information suggests that the great demand for wood led to serious deforestation.
It is unlikely that these early civilizations were concerned about preserving their forests, or for that matter about preserving any part of their environment. Rather they were proud of their ability to triumph over nature through their buildings, canals, and metalworking. The artwork and writing of the Sumerians reflect this attitude. For example, the ancient Sumerian story of the earth’s creation describes a battle between Tiamat, the female monster of chaotic nature and Marduk, the champion of the new order of the gods. Marduk slays Tiamat and builds a “city of the gods” in the sky. The story reflects the concept of a city as a model of divine order with its trim buildings and straight streets, while nature in contrast is chaotic. A wall of 9.6 km length encircling Uruk was built as much as a divider between urban civilization and the wilds of the outside world as much as it was to protect the city from attackers.

Disregard for the environment was a serious problem, but it was not the only one. Historians have noted that many civilizations in this part of the world flourished during a time known as the Neolithic Wet Period that began prior to 7000 BCE and ended in stages in the period 2900-2350 BCE. Precipitation was greater during this interval of four millennia than either before or after it. The Neolithic Wet Period ended not with a return to normal precipitation, but with a severe drought beginning around 2200 BCE that affected wide regions of the eastern Mediterranean and beyond. In southern Mesopotamia, the combination of the drought and environmental degradation took its toll. Salt in the irrigation water and the soil of the Sumerian fields had built up to high levels by this time. The salinity was made worse by deforestation in the surrounding mountains, which exposed salt-bearing rocks to rainfall. In addition, accumulation of silt in the canals over time caused poor drainage, making it difficult to leach the accumulated salt with the addition of more fresh water. Much of the agricultural land was a considerable distance from the flood plain of the rivers and thus received very little water other than what was provided by irrigation. Crop yields declined from 2400 BCE to 1700 BCE, and ultimately the civilization could not feed itself and collapsed: the population fell precipitously, urban dwellers migrated to rural areas in search of food, and industrial as well as agricultural activities were closed or scaled back to minimal levels.

The disintegration of the Sumerian economy is but one of several civilizations that suffered hardship around this time. The ancient civilization at Levant in modern-day Syria fell in the period 2200 BCE to 1700 BCE, and the Harappan civilization in northwest India, which was active in trading with the Mediterranean region, experienced collapse over the period 1700 BCE to 1500 BCE. It has been proposed that the civilizations occupying the land mass from Greece and Egypt eastward to India represent essentially a “world system” at this time, having most of the global economic output. The failure of these economic systems is hypothesized to result from the combination of environmental damage caused by human activities and natural variability in climate (such as droughts), as well as other earth system changes. The environmental damage results from such activities as overcultivation, overgrazing, deforestation, contaminating the landscape through mining, and poor water management.

2.1.2 Ancient Egypt

The beginning of a highly productive civilization in ancient Egypt began around 3300 BCE. While the Sumerians were building canals and irrigating cropland in Mesopotamia, the Egyptians were...
taking advantage of the Nile River to establish their system of agriculture. Like the Sumerians, the Egyptians constructed canals to bring water from the Nile to their fields during all seasons. In fact, the two civilizations traded with each other and shared their technologies. But most of the Egyptian fields were on the flood plain of the Nile, and the Nile flooded with striking regularity in late July or early August every year (21). This flood deposited rich alluvial soil from the upstream mountains and swamps onto the fields, and ensured continual nutrients to nourish the next year’s crops. The Egyptians also cultivated flax to make linen for clothing. They used mud from the banks of the river, dried in the sun or in kilns, to make bricks and pottery. Reeds growing around the Nile were used to make papyrus, a form of paper. The Egyptians developed hieroglyphics, their written language, on stone and papyrus. The paints used for hieroglyphics and other artwork were made from various naturally occurring minerals as well as plants (22). For example, black paint was made of carbon such as soot from fires, blue paint was from the copper-containing minerals azurite and malachite, and red paint was produced from iron and lead oxides.

The Egyptians learned metallurgy from the Sumerians, and then improved on it. They made many implements from copper – dishes, cookware, saws, chisels, knives, as well as hoes and sickles (23). They also made copper-arsenic bronze and copper-tin bronze. But the Egyptians are perhaps best known for their metalworking in gold. Many of the pharaohs were buried with gold ornaments, as such ornaments were among their most prized possessions. Unfortunately, knowledge of this fact led to pillaging of many of their tombs (24).

Enormous amounts of resources were needed to construct the ancient pyramids beginning in around 2650 BCE. The largest pyramids, those built for the pharaohs Khufu and Khafré roughly a century later, are located at Giza which is just south of modern-day Cairo (25). Two smaller pyramids are nearby, namely those of the pharaohs Menkaure and Khentkawes. The pyramids were constructed of different types of limestone and granite. The main quarry for limestone was located in Giza, and this local stone was used for much of the construction. However, higher quality limestone for the outer casing of the pyramids was taken from Turah on the east side of the Nile Valley. Granite was quarried from Aswan, 934 km south, and brought by boat to Giza.

To cut the limestone, the Egyptians used tools of wood, stone and copper (25). A typical core block of limestone for a pyramid was about 1 cubic meter in volume, weighing 2.5 metric tons (26), although some stones at the pyramid base were much larger and others, near the top, were somewhat smaller. Workers had to cut channels into the stone wall of the quarry all around the desired block, and then use a giant wooden lever to break it free and pry it out. Sockets for these levers are still visible in the quarry walls, illustrating the size of the levers needed (25). For quarrying granite, which is harder than limestone, workers used tools made of dolerite, a very hard rock. Workers then loaded the stone block on a sled and pulled it with ropes along a smooth, hard hauling track to its destination, with other workers pouring a lubricant, such as water, just in front of the sled to reduce friction (26). Upon reaching the construction site, workers had to haul the stone up ramps to reach the desired location on the pyramid. Mortar made by heating gypsum in a kiln was then mixed with water and applied to the stone surface, and the stone was set into place. Unfortunately, the invention of the wheel, occurring sometime prior to 3500 BCE in Mesopotamia (27), had not reached Egypt in time for construction of the pyramids at Giza.
Let us consider the resources needed for this operation. Wood was used to make the quarry levers, sleds, hauling tracks, and ramps. Wood was also used as fuel in smelting ores to make copper and bronze, and for making mortar. There were additional uses of wood, such as for shoring of underground mine shafts and for constructing the buildings of the metalworking industries. Of particular interest, wood was needed to make the boats that hauled granite from Aswan to Giza. Some of the wood used in constructing the boats had to be imported from Lebanon where large, sturdy cedars were available (28). Because of their expense and scarcity, cedar timbers were stitched together with rope so they could be taken apart and re-used. And when the cedar timbers reached the end of their useful life as boating material, they were used to make sleds.

Copper, arsenic, and tin were used to make copper and bronze tools for quarrying stone and making other tools of construction. Limestone was used not only as construction material for the pyramids but also for the hauling tracks: wooden timbers were positioned as bedding and then a layer of limestone chips mixed with mortar was applied over the timbers to make solid hauling tracks as wide as 11 meters at some locations (29). Clay was used to make pottery for carrying water for the mortar and also for lubricating the hauling tracks.

None of this includes the resources needed to feed and house the workers. There were roughly 20,000 to 30,000 workers at Giza at any one time during construction of the pyramid of Khufu (26). Construction lasted on the order of 20 years, which is reasonable considering that the pyramid consists of roughly 2.3 million stone blocks, each of which had to be quarried, transported to the site, and lifted into place.

Some of the earliest graffiti is found on Menkaure’s pyramid temple, written around 2500 BCE. The graffiti identifies the names of two crews working on the pyramid: the “Friends of Menkaure” and the “Drunkards of Menkaure” (26).

The years of the pyramid construction at Giza were highly productive in Egypt. Food was abundant, the population grew, and progress was made in developing arts and language. When the Neolithic Wet Period ended and the drought began around 2200 BCE, the Nile no longer flooded annually, causing fluctuations in agricultural output. The Egyptians experienced food shortages, and the population declined. These hardships are reflected in the biblical passage where Joseph interprets the Pharaoh’s dream as an omen of upcoming famine, warning the Pharaoh to store large amounts of grain (21, 30).

Unlike the Sumerians and several other civilizations, however, whose agricultural systems collapsed and caused the end of their civilizations, the Egyptians were able to continue producing food. The second millennium BCE in Egypt included times of plenty interspersed with times of want, but the civilization continued. Pyramids were built and pharaohs were celebrated. Among the most famous of the pharaohs was Tutankhamen who died in 1324 BCE. When the heavily fortified tomb of Tutankhamen was opened in 1922, archaeologists found a solid-gold casket of more than 100 kilograms as well as numerous other gold artifacts, showing the tremendous wealth of the pharaohs (22). This wealth made Egypt the envy of many other civilizations around the eastern Mediterranean.
Resources, especially wood, continued to be used in great quantities. Besides metalworking, considerable amounts of wood were used as fuel for the rapidly growing production of glass. The use of silica (e.g., sand) to make glass in Egypt dates back to around 1500 BCE (31). Glass vessels were especially popular. Various minerals were added to produce color in the glass; recent analysis of the soda content (sodium carbonate) and lime content (calcium carbonate or calcium oxide) of the ancient glass shows that workers had a good understanding of the glass-making process.

The period beginning in 1200 BCE and lasting more than three centuries was noteworthy in that a second severe drought influenced Egypt and the entire eastern Mediterranean (18). As with the earlier drought in 2200 BCE, many civilizations around the eastern Mediterranean suffered economic decline (32). The drought made the Egyptian civilization vulnerable to attack from the outside (21). In fact, Egypt was conquered several times in the first millennium BCE, although it managed to retain many of its customs and activities even while under foreign control.

The ancient Egyptian civilization ended in 30 BCE when Egypt became a province of the Roman Empire. Although still productive, the country had changed compared with three millennia earlier. Deforestation was severe, especially since the Egyptians grazed their domesticated animals on land cleared of wood, guaranteeing that any new growth of trees would be immediately eaten. These trees were not large even in ancient times; the quantity of cedar imported from Lebanon attests to the need for larger timbers for the elaborate construction. But imports were also limited at times: in the middle 1600’s BCE, the tradition of burials in large sarcophagi made of imported Lebanon cedar was replaced by burials in much smaller coffins of local sycamore, due to the scarcity of high quality imported wood (33). Large game such as elephant, rhinoceros, giraffe, and gerenuk gazelle were rare or missing in the northern part of the country, and the wild camel was extinct (21). Natural vegetation in the Nile Valley had been largely replaced by land cultivated with crops for human consumption and land for grazing domesticated animals. Although the Egyptians understood the importance of natural cycles, since their livelihood revolved around the annual flooding of the Nile, their appreciation for the critical role of ecosystems in preventing desertification was absent. Many historians have written about natural changes in climate over the three millennia of ancient Egypt, and certainly these changes played a role. But the impact of the civilization on the functioning of natural systems even in these early times cannot be ignored.

2.2. The Iron Age up to 600 A.D.

2.2.1. Ancient Greece, 1400 BCE to 300 BCE

While the early Egyptian pyramids were being constructed, the Minoan culture was developing on the island of Crete. The Minoans had a thriving economy by 2200 BCE, with highly productive mining and agriculture, and with many large palaces and other buildings. However, battles with a growing population on the Greek mainland, the Mycenaeans, eventually led to their downfall in around 1400 BCE. It was at this time that the Mycenaeans developed the first great civilization in ancient Greece.

The Greek kingdoms under the domination of the Mycenaeans during 1400-1100 BCE further developed use of the earth’s resources, especially stone, metals, and wood. Entry into the massive walled city of Mycenae was through the “Lion’s Gate,” named for its stone sculptures. Roads of
stone were built into the countryside. Craftsmen made clay pottery as well as ornaments of ivory and gold. Rich deposits of tin from what is now Cornwall in Britain were mined and imported to Greece for making bronze (34). The civilization is perhaps best remembered for their legendary war against the city of Troy around 1200 BCE. The story of the Trojan War was described in The Iliad by Homer around 800 BCE, and then continued in The Aeneid written by Virgil in 19 BCE (35). According to The Aeneid, Mycenaean soldiers hid inside a large wooden horse which the Trojans brought inside their gates, unthinkingly accepting it as a gift, only to be conquered by the soldiers once inside the city. This is one of many battle stories; it is clear that resources were important to the Mycenaens for implements of war.

Iron smelting was discovered in the eastern Mediterranean region around 1400-1300 BCE (36), and became significant in the area by 1200 BCE. The latter date is considered by many historians to mark the end of the Bronze Age and the beginning of the Iron Age in this part of the world. The discovery of iron was to play an important role in ancient Greece centuries later, as explained below. The location of the earliest ironwork is unknown, but it may have been in Cyprus, where steel knife blades from the twelfth or eleventh centuries BCE have been excavated, or in Northern Anatolia along the Black Sea (37).

Iron probably came into use as a byproduct of smelting other metals such as copper (38). The reduction of iron ore to pure metallic iron requires the addition of carbon monoxide as the ore is heated. But the use of hematite as a flux for smelting copper, as discussed in section 2.1.1, would have introduced iron ore into a high temperature environment, and the reaction of charcoal with oxygen during copper smelting would have created enough carbon monoxide to reduce the hematite to pure iron (37). Thus metallic iron was probably an unexpected output of copper smelting.

Iron is more complicated to work with than copper. Pure iron is much weaker than bronze, but trace amounts of carbon introduced into the iron can greatly increase its strength. This carbon-containing iron is essentially steel which is much stronger than bronze. Because iron melts at a temperature of 1500°C, which is not achievable in simple wood fires, the ancients had no easy way to increase the carbon content. However, by heating the iron for a long time in a charcoal fire, there was time for the carbon atoms to diffuse into the surface of the iron, a process known as carburization. The ancient metalworkers used this method to produce sheets of carburized iron that in some cases were very strong but also very thin, since the carbon atoms could not penetrate the iron deeply. They then joined the sheets by heating them to over 800°C and hammering them together to create a laminate (37). They also found that they could add strength to the carburized iron by quenching it in cold water rather than allowing it cool gradually. If the material is subsequently reheated to a moderate temperature, it becomes even stronger.

Of course, the ancients did not realize why extended heating in a charcoal fire strengthened their iron sheets; they may have thought they were purifying the iron. Since they could not control the amount of carbon, and indeed did not even know that carbon diffusion was responsible for the added strength, producing carburized iron that was stronger than bronze required a bit of luck. They also had to experiment to learn that quenching and reheating added further strength to their product.

The Mycenaees were warlike people: many of their metal resources were used for armor and weapons. By 1200 BCE, wars among the Grecian cities had strained resources to the limit. Even
more important was the drought that began at this time, discussed in section 2.1.2 (18). As the
drought weakened civilizations throughout the eastern Mediterranean, people to the North saw new
opportunities for conquest. Their attacks added to the overall instability. The result was a collapse
of the Mycenaean civilization as well as other civilizations in the region (32). With the lack of
international trade due to economic collapse, it was impossible to import tin from Cornwall to make
bronze for weapons or for the tools of agriculture. The shortage of bronze forced metalworkers in
Greece to recycle bronze religious vessels to make weapons for fighting off the invaders. Mass
migrations from Anatolia southward due to the invasions included metalworkers skilled in making
iron. Both the shortage of bronze and the migration of skilled metalworkers accentuated the growth
of iron after 1200 BCE (37). Eventually, iron replaced most uses of bronze.

Recovery from the economic decline was slow and painful. Eventually, the rise of new farming
tools made of iron helped to boost agricultural productivity. Lifestyles improved over the period
800 BCE to 600 BCE, and the Greek city-states were established. Conquests began again, as Greece
colonized lands around the Mediterranean to obtain resources such as cropland, grazing land, and
metals (39). Forested land in Greece, which had recovered somewhat from deforestation during the
second millennium, was again denuded for metalworking. Roughly one million acres of woodland
were needed for a single metallurgical center at this time. Additional timber for construction of
grandiose public buildings came from locations around the Mediterranean and from Asia as far
away as India. Severe environmental degradation occurred with the operation of the silver mines at
Laurion near Athens which employed over 11,000 workers. The wealth of the industrial operations
in Athens was instrumental in supporting their navy which boasted several hundred ships (39, 40).

While the Greeks were moving into new areas, Persia had grown to become one of the largest
empires in history, with land stretching from Pakistan to the Balkan peninsula by the late sixth
century BCE. In 490 BCE, Persia attacked Athens in the Battle of Marathon, of historical
importance because the stronger metal armor of the Athenians helped them win over a much larger
force of Persians. Many additional battles followed, and the Greek city-states ultimately defeated
Persia. Athens became a formidable sea power, with its colonies spreading from the Balkan
peninsula to include regions in Spain and France, parts of Italy, coastal areas on the Black Sea, the
eastern shore of the Mediterranean, and parts of northern Africa.

Pericles came to power in the 450s BCE and brought new heights to civilization in Athens. The
magnificent buildings of the Acropolis, especially the Parthenon, were constructed of marble, and a
large statue of Athena adorned with gold and ivory dominated its interior. An advanced government
with representation by both rich and poor was developed. Daily life was dominated by agriculture
and craftsmanship, with the farmlands supporting an urban population over 100,000 in a city whose
walls were at no point more than 1.6 km from the central Acropolis.

Deforestation became a serious problem. As in ancient Egypt, once trees were cut, the land was
used for grazing livestock which prevented re-growth of the trees. These practices led to serious
economic disruptions and later contributed to the decline of Athens and other Greek city-states.

Athens was not the only city-state with over 100,000 inhabitants; Corinth and Syracuse also had
such large populations. Given the size of these cities, the ancient Greeks obviously needed to be
concerned about waste disposal. Archaeological finds indicate that networks of sewers carried
stormwater as well as residential wastewater, and any other waste left in the streets, out of the city and in some cases out to sea. However, the limited data available make it difficult to know details of waste disposal, such as how much was disposed on land and how much in bodies of water. Nevertheless, it is clear that waste disposal in the ocean, even massive amounts of waste disposal, was considered acceptable practice (41).

One can obtain more insight into the environmental attitudes of the ancient Greeks by considering writings of the leading philosophers of the day. For example, the Greek philosopher Protagoras stated “Man is the measure of all things.” Yet many artists and philosophers at this time believed in the importance of the natural world, with some artists imitating nature in their artwork.

The Greek philosopher Plato, 429-347 BC, wrote in some detail of the deforestation around Athens (42). He also wrote about the dangers of becoming too dependent on material goods, noting that such dependency leads to resource wars (43), and wrote of the unity between the microcosm of human life and greater order of the universe (44). One of Plato’s students at the Academy was Aristotle, 384-322 BC, who developed lectures and writings in many disciplines that have influenced scientific and philosophical discourse up to the present day (45). In Politics, Aristotle discusses three categories of wealth. The first category is the natural economy which includes growing crops, tending herds or flocks of livestock, hunting, and the like, where plants and animals are reproducing naturally, and whose products have intrinsic value. The second category is the unnatural economy which includes retail trade, or wealth gained merely by exchange and taking profit. Aristotle notes that in this second category, people are merely extracting riches from each other rather than engaging in an activity that converts a natural resource into a product with value. The third category is partly natural, and this includes extractive industries such as mining. Producing a metal from ore does make use of a natural resource which is converted to an object with value. However, the resource is not growing or reproducing and yet it is being sold for profit. Such an activity is inherently unsustainable.

Aristotle also developed a sophisticated classification of animals based on careful observation of their physiologies (45). He was able to explain the earth’s hydrologic cycle, and wrote about changes in the continents and oceans over geological time scales. Much of what we know about the biosphere today, which plays a role in modern discussions on sustainable human development, had its beginnings in Aristotle’s original work.

Despite the wisdom of its philosophers, the decision makers in Athens did not pursue a sustainable trajectory. When its local forests were used up, the Athenians took over forested land further away, continuing to exploit resources without concern for their natural replenishment. Ultimately, the civilization could no longer support itself. It was replaced by another great civilization which we now consider.
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38. op. cit., ref. 5, pages 878 and 882.


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