Carrying Capacity: Genesis, History and Conceptual Flaws

Nathan F. Sayre
Department of Geography
507 McCone Hall #4740
Berkeley CA 94720-4740

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Introduction

Carrying capacity may be the most versatile and widely popularized concept in environmental politics today. Like sustainability—which it predates and in many ways anticipates—carrying capacity can be applied to almost any human-environment interaction, at any scale, and it has the additional advantage of conveying a sense of calculability and precision—something that sustainability thus far lacks. Indeed, scientists of many kinds have calculated carrying capacities—in range and wildlife management, chemistry, medicine, economics, engineering and population biology, for example. In political debates, carrying capacity serves to help justify hunting—as in the figure on the title page—and it is also often used to support neo-Malthusian arguments regarding the finitude of the world's resources relative to growing human numbers. In both contexts, its authority is buttressed by association with the work of prominent ecologists, including Aldo Leopold, Eugene Odum, Garrett Hardin and Paul Ehrlich—the last two having explicitly declared that the world's carrying capacity for humans is being exceeded.

But the origins of carrying capacity are not found in Malthus—he never used the term—nor even in debates about population (human or otherwise), unless one were to argue that the idea associated with it today is more definitive than the term itself. It is true that in 1820 William Godwin published a calculation of the number of humans the world could support, in *Of Population*, his polemical response to Malthus. Godwin took contemporary China as demonstrating the maxima of possible cultivation and population density, which he then extrapolated to the earth's habitable area, arriving at a figure of nine billion people. Clarence Glacken states that Godwin's was one of the earliest attempts to specify such a number, and the estimate may now appear prescient. In context, however, Godwin was mocking Malthus, and he nowhere referred to his estimate as a carrying capacity. In fact, the term was not applied to questions of global human population until the 1940s, after a century of serving various other purposes.

Where did carrying capacity come from? How was it originally conceived, and to what extent have its origins shaped its subsequent history? No one has answered these questions; as far as I can tell, they have scarcely been posed. The term is used in an unusually wide range of fields, but its origins are remarkably obscure. Scholars have assessed its history within wildlife management,[1] and rangeland ecologists have challenged its assumptions in relation to livestock grazing.[2] But neither field has recognized that the origins of carrying capacity lie elsewhere. Karl Zimmerer asserts in passing that the concept was "[f]irst established in laboratory experiments with cultured microorganisms during the nineteenth century,"[3] but he provides no support for the claim, which I have been unable to substantiate. Carrying capacity seems to have an intuitive conceptual obviousness, such that few people feel a need to scrutinize its history, assumptions or coherence.

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[1] Christian C. Young 1998. Defining the range: The development of carrying capacity in management practices. *Journal of the History of Biology* 31: 61-83; R.Y. Edwards and C. David Fowle 1955. The Concept of carrying capacity. *Twentieth North American Wildlife Conference*.
[2] See below.
[3] Karl S. Zimmerer 1994. Human Geography and the "New Ecology": The Prospect and Promise of Integration. *Annals of the Association of American Geographers* 84(1): 112.

This paper examines the genesis and history of carrying capacity in order to destabilize this obviousness, to understand its extraordinary persistence and rhetorical potency and, in so doing, to reveal its conceptual flaws. One can classify the uses of carrying capacity into four major types since the term was coined in the first half of the nineteenth century. The only definition that would capture all of them would be something like "the maximum or optimal amount of a thing or organism that can be conveyed or supported by some encompassing thing or place." At its origins, carrying capacity referred to a *fixed quantity* of *X* that some encompassing *Y ought* to "carry" in abstraction from time or history. Since then, it has sometimes described a maximum limit and more often an optimal or normative one, but it has always aspired to *idealism, stasis* and *numerical expression*. Only in the first of the four types of uses were these attributes justified, however, and even then only imperfectly; only the most astute of its subsequent proponents—Leopold in particular—have recognized the contradictions that arose as they extended carrying capacity to realms in which no such relation between *X* and *Y* actually existed. Each new use appropriated the basic idea and, in some measure, the authority of its predecessors while overlooking—and ultimately forgetting—their contexts and limits. The concept has served important heuristic or theoretical purposes in scientific research, but when deployed by institutions of the state—as has usually been the case—carrying capacity has often resulted in grievous errors of policy, administration, resource management and ethics.

1: We call it "payload"

Carrying capacity originally referred to mechanical or engineered attributes of manufactured objects or systems.[4] It arose first in the context of shipping, apparently triggered by a disparity introduced into tariff laws by the advent of steam power. Since the fifteenth century, "tonnage" had referred to duties imposed on cargo by volume (a "tun" being a cask of wine); it was often paired with "poundage," a duty calculated by weight. Tonnage was not determined by measuring cargo, however. Rather, each ship was measured from the outside and its tonnage was estimated by a series of calculations. This figure became an attribute of the ship itself: Duties were imposed on the ship according to its tonnage, regardless of how much cargo it carried on any particular voyage. Over time, "tonnage and poundage" appears to have coalesced into the single term, tonnage, and to have gravitated in meaning from the duty to the vessels themselves. The *OED* includes this phrase from 1751: "Of more Tonnage or Capacity than a Man of War of 40 Guns."

[4] A note on methods. Until recently, this research would have required the kind of exhaustive review of texts that produced the *Oxford English Dictionary* (which contains no entry for carrying capacity). In this case, it instead relied on digital technology. Search engines were asked to find the term "carrying capacity," and the results were then sorted chronologically. This of course runs the risk that earlier uses were not discovered due to incomplete digitization. Several of the relevant journals and archives have been digitized much further back in time than the first uses of the term found by the searches, however, and additional research was conducted "manually" in those fields that appeared to have produced the earliest uses of the term. It remains possible—even likely—that earlier uses of "carrying capacity" may be found, but I am reasonably confident that the chronology presented here is basically sound. The relative shortage of digitized newspapers from before 1900 is a particular problem in this regard.

The earliest use of the alliterative “carrying capacity”[5] that I have found is from 1845, in a report by the US Secretary of State to the Senate on “changes and modifications in the commercial systems of foreign nations.” It included a copy of an act passed by the Republic of Texas in February of the preceding year, which imposed “a tonnage duty of one dollar per ton.” The Secretary reported that the previous duty—sixty cents per ton on sailing vessels, thirty cents on steamboats—had been imposed “according to register tonnage,” whereas the new law would be applied to steamboats “according to their carrying capacity only.”[6] The distinction is hard to discern—“register tonnage,” according to the *OED,* was a measure of volume that already subtracted certain non-cargo spaces (crew’s quarters and engine rooms) from a ship’s volume.[7] Some light is shed on the matter by another report, from the President to the House of Representatives nine years later. Describing a dispute over duties imposed by Spanish authorities on English and American cargo ships, the report stated:

Being side-wheel boats, and using sails only as auxiliaries, they [the steamers “Black Warrior” and “Cahawba”] are obliged to steam during the whole passage. Moreover, as a large portion of their holds is taken up by the boilers and other necessary machinery, their carrying capacity is very small in proportion to their tonnage. The “Tamaulipas” is a propeller, built in England, with a view to carrying merchandise principally. She is a sailing-vessel, and only uses her propeller as an auxiliary when the winds are unfavorable. She measures very small, but her carrying capacity is very large in proportion.[8]

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[5] Whether carrying capacity would have enjoyed such a long and varied life without alliteration is an interesting, if altogether academic, question. I should mention here that I have not yet had a chance to study Pierre-François Verhulst’s work in the original French (see section 3 below), and there is a remote chance that he coined a similar term (*capacité de porter*?) that would have lacked alliteration.

[6] Letter from the Secretary of State, showing the changes and modifications in the commercial systems of foreign nations. January 13, 1845. Serial Set Vol. No. 456, Session Vol. No. 7, 28th Congress, 2nd Session, S. Doc. 135.

[7] A ton equaled 100 cubic feet. Different countries used different methods to calculate a ship’s tonnage, however, so the *OED* definition may not have applied in Texas.

[8] Case of the Black Warrior, and other violations of the rights of American citizens by Spanish authorities. Message from the President of the United States, transmitting a report in regard to Spanish violations of the rights of American citizens, &c. April 6, 1854. Serial set Vol. No. 724, Session Vol. No. 11, 33rd Congress, 1st Session, H. Exec. Doc. 86.

The advent of steam ships necessitated a new means of reckoning duties, one that compensated for the much greater volume of the new technology compared to sailing vessels. It may have been prompted, in particular, by the large quantities of fuel and fresh water needed for steam propulsion, since these burdens were not deducted in calculations of register tonnage. Fairness—from the point of view of steamboat proponents, at least—required levying each ship according to the amount of cargo it could convey, rather than a measure derived from the ship's overall size—a measure that had never been perfect but nonetheless sufficed when all cargo ships were wind-powered. Carrying capacity captured this distinction.

Disputes over trade remained the dominant context for the use of carrying capacity until the 1880s.[9] In 1863, an article in the *Journal of the Statistical Society of London* defended the rapid growth of the British merchant fleet—"the increased size of British ships, the increasing economy of labour in their navigation, the greater rapidity in their movements, their increased carrying capacity, and especially the great development of steam tonnage"—while decrying "the foreign tonnage increase" as "exorbitant; not based on trade demand, but on political expectations."[10] An 1875 discussion, published in the same journal, remarked on "the decrease in the carrying capacity of the sailing vessel and the

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[9] Typically the disputes were international, but not always. In 1867, the US Supreme Court settled a dispute between the federal government and the state of Iowa in which the carrying capacity of ships on navigable rivers was a central issue: vessels over ten tons in carrying capacity—and by extension, the rivers they used—were judged to fall under federal jurisdiction. Supreme Court of the United States. The Steamboat Admiral Hine v. Matthew R. Trevor, by J.F.D. *The American Law Register* (1852-1891) 15(10), 1867, p.595.

[10] On the Statistics of Tonnage During the First Decade Under the Navigation Law of 1849, by John Glover. *Journal of the Statistical Society of London* 26(1), 1863, p.17.

increase in carrying capacity of the steamer" in the preceding five years.[11] How to measure and assess wind- versus steam-powered commerce was a preoccupation of British statisticians for years to come, in which carrying capacity served as a categorical alternative to tonnage.[12]

If carrying capacity distinguished the amount conveyed by a ship from the ship itself, it was logical to extend it to other means of conveyance, especially as railroads and other systems of transport and communication were developed during the late nineteenth century. Thorstein Veblen noted that "an increase of the carrying capacity of the Erie canal" had contributed to lower grain prices in the quarter-century up to 1892.[13] Eventually, the term shed its connection to the levying of duties—which still attaches to tonnage—and became simply a measure of how much *X* an inanimate *Y* could carry. In 1879, Lord Dunraven applied the term to canoes:

Civilized nations have passed and left no sign, but the Indian will be remembered by two things at least—the birch-bark canoe, which no production of the white man can equal for strength, lightness, gracefulness, sea-going qualities and carrying capacity; and the snow-shoe, which appears to be perfect in its form and, like a violin, incapable of development or improvement. There are three inventions which the ingenuity of man seems to be unable to improve upon, and two of them are the works of savages—namely, the violin, snow-shoes, and birch-bark canoes.[14]

An 1894 paper in *The Geographical Journal* described cedar canoes in Canada that had "a carrying capacity of about 1800 pounds," suggesting that the term was coming to be

[11] The Mercantile Navies of the World in the Years 1870 and 1874 Compared, by Henrry Jeula. *Journal of the Statistical Society of London* 38(1), 1875, p.85.
[12] See, for example, the discussion that follows Tonnage Statistics of the Decade 1870-1889, by John Glover. *Journal of the Statistical Society of London* 45(1), 1882, esp. p.65.
[13] The Price of Wheat Since 1867, by Thorstein B. Veblen. *The Journal of Political Economy* 1(1), 1892, p.87.
[14] Meeting at Chickering Hall. Moose and Cariboo Hunting in Colorado and Canada, by Lord Dunraven. *Journal of the American Geographical Society of New York* 11, 1879, p.367.

associated with weight, rather than volume.[15] But other units of measurement were also possible, depending on the topic under consideration. An 1881 paper in *Science* used people per unit time to describe the electric railroad in Paris:

…the capacity for transportation of the electric road is so great, that we with some difficulty accept the given figures, while it is easy to try the exactness of them. Thus, every minute a carriage, with places for 50, passes each station; so that, if the carriages are always full, there will be 100 persons carried each minute in the two directions, and if we take account of the additions during the journey, we will have about twice as much; that is about 200 persons every minute, or 12000 per hour. But it is possible to still increase the carrying capacity…[and] arrive, in this case, to the colossal figure of 24000 persons an hour.[16]

Any man-made system lent itself to such an appraisal, particularly as the scale and rate of movement eclipsed earlier notions of what was physically possible and threatened to exceed what a person could directly observe and (therefore) believe. The capacity of irrigation ditches and pipelines to carry water; of hot air balloons to carry weight; and of lightning rods and transmission lines to carry electricity were all measured and reported as carrying capacities in the last decade of the nineteenth century.[17]

In all these cases, carrying capacity was a quantitative measure of a man-made object or system; it could be calculated and predicted with reasonable (if not perfect) precision. Most of these uses of the term persist to the present, especially among engineers, although they are relatively unfamiliar to biologists and social scientists. In common parlance, this meaning of carrying capacity has migrated to the term "payload" (itself derived from the amount for which one is paid to haul something). And just as one can

[15] An Expedition through the Barren Lands of Northern Canada, by J. Burr Tyrrell. *The Geographical Journal* 4(5), 1894, p.439.
[16] Electric Railroads in Paris. *Science* 2(71), 1881, p.526.
[17] *Harvard Law Review* 5(7), 1892, p.353; The Colorado Doctrine of Riparian Rights, and Some Unsettled Questions, by Charles E. Gast. *The Yale Law Journal* 8(2), 1898, pp.80-81; *Science* 6(138), 1897, pp.291-292; *Science* 17(432), 1891, p.269.

carry more weight in a truck than its official payload prescribes, carrying capacity in this use is a fixed ideal, abstracted from the variable amounts that any particular ship, railroad, truck or power line might actually carry at a given moment in time. It refers to the amount of *X* that *Y* was *designed* to carry.

2: Range and Wildlife Management: Carrying capacities of living organisms and natural systems

When carrying capacity was first applied to living organisms and natural systems, in the 1870s, it retained its literal sense of conveying or transporting some *X*, while *Y* was expanded to include animals and humans; subsequently, it was applied to such things as rivers and the wind. In an 1873 monograph published in the *Transactions of the American Philosophical Society*, William Gabb described the hunting practices of the natives of Santo Domingo: "Their custom is to bring into the mountains a supply of salt, and then stay, killing wild pork and beef and drying the meat so long as the salt lasts, or until they reach the full carrying capacity of their animals."[18] Here, carrying capacity was a measure of how much meat the natives' pack animals could carry back from the mountains at the end of the season. Ten years later, the same application was made to "the *genus homo"*:

> His carrying capacity was limited to what his two hands would hold. Vessels and receptacles of every kind were for the future to devise… While, without some such expedient, man was limited in his carrying capacity to a pebble in each hand, he found

[18] On the Topography and Geology of Santo Domingo, by William M. Gabb. *Transactions of the American Philosophical Society* 15(1), 1873, p.127.

that, by securing a slender thong to each, he could carry (or drag) quite a number in each hand.[19]

In the *Botanical Gazette* of 1887, the legs of certain bees were said to have a carrying capacity for the pollen of specific flowers: “After a corpusculum is fastened to every available process the carrying capacity of the leg is still indefinitely increased.”[20] *The American Naturalist* of 1896 referred to “the carrying capacity of the walls of the vessels” through which water moved in cucumber plants.[21] Such uses persisted well into the twentieth century, and they are still common in some fields.[22] In relation to animals and humans, however, they now seem anachronistic or crude.[23]

About a decade later, the realm of possible *Y*s was extended further to include inanimate natural phenomena. An 1888 article in *Science* referred to the carrying capacity for floodwaters of the main channel of the Atchafalaya bayou in Louisiana,[24] and a 1901 article in the *Botanical Gazette* referred to “the moisture-carrying capacity of the winds” there.[25]

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[19] Sixty-Fifth Regular Meeting, February 20th, 1883. *Transactions of the Anthropological Society of Washington* 2, 1882, p.84.
[20] Insect Relations of Certain Asclepiads, I., by Charles Robertson. *Botanical Gazette* 12(9), 1887, p.214.
[21] The Path of the Water Current in Cucumber Plants, by Erwin F. Smith. *The American Naturalist* 30(354), p.451.
[22] The oxygen-carrying capacity of blood, for example, can be found in recent medical journals.
[23] As recently as 1961, a scholarly article presented a table of data described as showing “a great increase of carrying capacity between 1943 and 1946” in Costa Rica—measured in cubic meters of stone moved per worker and attributed to improvements in diet. The World’s Hunger and Future Needs in Food Supplies, by P.V. Sukhatme. *Journal of the Royal Statistical Society* Series A 124(4), 1961, p.492.
[24] Prevention of Floods in the Lower Mississippi. *Science* 12(290), 1888, p.85.
[25] The Ecological Relations of the Vegetation of Western Texas, by William L. Bray. *Botanical Gazette* 32(2), 1901, p.113.

These extensions appear, in hindsight, to have ushered in the second major type of carrying capacity by a subtle but significant transposition. It occurred first in discussions of livestock, as in this 1886 discussion of "acclimatization in New Zealand":

The most important mammalian introduction into these islands has certainly been that of the rabbit…Brought into a country where only a few sluggish hawks existed as natural enemies, the rabbits have increased almost without let or hinderance, and now occur in millions. Ten years ago they were almost rare; now many districts of the South Island are quite alive with them…The surface of the ground is honeycombed, the vegetation in places eaten nearly as bare as a macadamized road, while the animals towards evening are met with by thousands. Their effect on the stock-carrying capacity of the country has been ruinous, and their abundance has seriously retarded settlement…The government is now trying what is generally considered to be a very dangerous experiment, viz., the liberation of weasels and stoats. If these creatures increase at all freely they will prove even a worse pest than the rabbits.[26]

The meaning of "carrying" changed from a literal to a much more figurative sense. What was previously a *Y*—the animals that carried things—became instead the *X* being "carried" by the land where they lived. By 1889, carrying capacity had become a measure of rangeland productivity:

Australian records show that land favored with less than ten inches of rain a year is quite valueless without irrigation. In such regions only one sheep per square mile can be carried for each inch of rainfall. For from nine to thirteen inches, however, the increase is about twenty sheep per square mile, and from thirteen to twenty inches of rainfall the increased carrying capacity is about seventy sheep per square mile.[27]

Australia and New Zealand became object lessons in the new use of carrying capacity during a period of widespread and severe overgrazing in the American West. Queen Victoria's government had instituted a system of grazing leases on Australia's vast rangelands, with lease fees and taxes based on the number of livestock they could support; this was reported to have spurred settlement by small, "yeoman" producers and increased investment in land improvements. Of a similar system in New Zealand it was

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[26] Acclimatization in New Zealand, by Geo. M. Thomson. *Science* 8(197), 1886, p.428.
[27] The Rainfall of the Pacific Slope. *Science* 13(332), 1889, p.458.

said: “The stock carrying capacity of the land and the wealth of the country was therefore by this process made seven or eight times what it was before,” much to the relief of English bondholders.[28] These examples helped inspire land legislation in Texas and later in the US West as a whole.[29] Soon, this new sense of carrying capacity was sufficiently well established that the earliest US range scientists, writing in the late 1890s, felt little need to explicate it.

The adoption of carrying capacity as the core concept of range management has been treated elsewhere; here, only a summary of key points is warranted. That such a thing as a fixed carrying capacity existed for any piece of rangeland was taken as given, although researchers in more arid areas soon complained that determining such a number was problematic. (Not until 1961 did range scientists publish the conclusion that “Sustained grazing capacity does not exist” on the semi-desert ranges of the southwestern US.[30]) A distinction was drawn between “original” carrying capacity (before the widespread overgrazing of 1873-1893) and “actual” capacity; the former was taken as fixed, whereas the latter reflected current conditions and could be increased by investments in revegetation, artificial water sources, or emergency forage supplies.[31] Definitions of carrying capacity from the time strongly resemble today’s “sustainability”—use that does

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[28] Notes on the Progress of New Zealand for Twenty Years, 1864-84, by Robert Stout. *Journal of the Statistical Society of London* 49(3), 1886, p.574. Cf. Land Systems of Australia. Review author Arthur Duckworth. *The Economic Journal* 5(17), 1886, p.79; Australasia, by H.E. Gurner, W.F. Craies, A. Buchanan, Edward Manson, John W. Fearnsides, and A.R. Butterworth. *Journal of the Society of Comparative Legislation* 1(3), 1899, pp.483-484. I have not found evidence that “carrying capacity” was employed in the formulation of these systems at their origins, but the question warrants further research.

[29] Potter and Coville, 1904. *Report of the Public Lands Commission*.

[30] Harold A. Paulsen, Jr. and Fred N. Ares, 1961. Trends in carrying capacity and vegetation on an arid southwestern range. *Journal of Range Management* 14(2).

[31] H.L. Bentley, 1898. Cattle ranges of the Southwest: A history of the exhaustion of the pasturage and suggestions for its restoration. USDA Farmer’s Bulletin No. 72; Jared G. Smith, 1899. Grazing problems in the Southwest and how to meet them. USDA Division of Agrostology Bulletin No. 16.

not result in long-term impairment—and the expectation was that grazing at "actual" capacity would allow natural recovery toward "original" capacity. Even "actual" capacity was deemed to be basically stable, however, and it was institutionalized in leases to graze *X* number of livestock on *Y* acres of land; fences fixed to the ground and credit secured against herds rendered allotments and stocking rates largely immune to adjustment.[32]

Clementsian successional theory is said to have inspired this system,[33] but historical support for the claim is weak. Clements himself explicitly rejected fixed carrying capacities,[34] and his theory appears to have provided a *post hoc* scientific rationale for decisions shaped principally by economic and political considerations.[35] The most thorough-going (and effective) critiques of carrying capacity have come from places outside the US—in particular Australia and Africa—after post-World War II pastoral development projects based on the US model proved almost uniformly unsuccessful.[36] The failures, both at home and abroad, can be traced directly to the idealism, stasis and numerical expression of carrying capacity as a concept—attributes that could be justified

[32] Nathan F. Sayre, 2002. *Ranching, Endangered Species, and Urbanization in the Southwest*. Tucson: University of Arizona Press, ch. .
[33] National Research Council, 1994. *Rangeland Health: New Methods to Classify, Inventory, and Monitor Rangelands*. Washington, D.C.: National Academy Press; Society for Range Management, 1995. New concepts for assessment of rangeland condition. *Journal of Range Management* 48: 271-282.
[34] Frederic E. Clements, 1920. *Plant Indicators: The Relation of Plant Communities to Process and Practice*. Washington, D.C.: Carnegie Institution of Washington.
[35] The US Forest Service explicitly prioritized timber production over grazing, and the national policy of aggressive fire suppression was intended to protect timber values. Static carrying capacities were instrumental to fire suppression, by ensuring that fine fuels (i.e., grass) would be minimal during drought periods, when fire risk was highest. Historical documents strongly suggest that Forest Service officials recognized this instrumentality (Earle Clapp, 1926. *A National Plan for Forest Research*). Fire suppression produced long-term degradation of both grasslands and forests across much of the West.
[36] Roy Behnke, Ian Scoones and Carol Kerven, eds., 1993. *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas*. London: Overseas Development Institute; Mark Westoby, 1980. Elements of a Theory of Vegetation Dynamics in Arid Rangelands. *Israel Journal of Botany* 28: 169-194; Mark B. Westoby, Brian Walker and Immanuel Noy-Meir, 1989. Opportunistic Management for Rangelands not at Equilibrium. *Journal of Range Management* 42: 266-274.

for a ship or a canal but were ill suited to highly variable rangelands. Yet it was precisely these attributes that made carrying capacity attractive to government agencies seeking stable administration, and to ranchers and bankers seeking to mortgage or capitalize leases. The same can probably be said of international development agencies such as the World Bank.

Less well known is how this use of carrying capacity was transferred from livestock and grazing management to wildlife and hunting management. A 1913 announcement in *Science* described the US Forest Service's newly organized research program this way:

> Under grazing, work is being done to collect basic information on the forage, to find methods of reseeding the more valuable kinds, both artificially and naturally, and ways of handling stock so as to increase the carrying capacity of the range, better the condition of the stock, and insure complete utilization of the forage.[37]

The quixotic relation to natural productivity—carrying capacity was at once fixed by nature, yet capable of being increased by "complete utilization" of the resource—aptly reflects the Forest Service's dual mandate to conserve and to utilize the nation's resources. During the 1920s and 1930s, early wildlife managers applied this concept of carrying capacity to wildlife in hopes of understanding and increasing the number of deer, quail and other game various places could produce.

The link is direct and specific: Aldo Leopold encountered carrying capacity in 1914-15, when he worked in the Forest Service's Office of Grazing. "The discovery would reverberate through his work for the rest of his life," beginning with the infamous

[37] Review of Forest Service Investigations, by Barrington Moore. *Science* 37(960), 1913, p.802.

collapse of the deer population on the Kaibab plateau in the mid-1920s.[38] After hunting was banned in the newly created Grand Canyon Game Preserve in 1905, and large predators such as wolves were systematically exterminated, the deer multiplied until they outstripped their food supply. The episode, which recurred later in Pennsylvania, Wisconsin and elsewhere, introduced an additional variable not considered in the livestock context: predators. And it provoked Leopold to take up—and in large measure create—the field of wildlife management.

The Kaibab deer had increased to huge numbers and then died of starvation, but this was disputed and far from easy to explain. In a vast, rugged and nearly unpopulated area, the exact number of deaths was virtually impossible to determine, and federal land managers ignored warnings about the problem for a decade—after all, this was a protected reserve, managed in large part for the deer. Hunters would have nothing of the idea that there could be "too many deer" anywhere, and ranchers resisted the argument that predator extermination had had anything to do with it.

Leopold's diagnosis of the Kaibab incident both relied on and challenged the concept of carrying capacity. Alongside Herbert Stoddard's pioneering research on the bobwhite quail, deer irruptions stood as one of Leopold's chief empirical examples as he wrote his landmark textbook, *Game Management*. The core question was the locus of the mechanism controlling game populations: was it inherent in the animals themselves, or

[38] Meine, Curt 1988. *Aldo Leopold: His Life and Work*. University of Wisconsin Press, p.136.

was it a function of external factors such as climate, vegetation, or competition? Carrying capacity, for Leopold, denoted the latter explanation:

> When the maximum wild density of grown individuals attained by a species, even in the most favorable local environments, tends to be uniform over a wide area, that maximum may be called the saturation point of that species.
>
> This is a different thing from the maximum density which a particular but less perfect range is capable of supporting. While this latter is literally saturation for that particular range, it is obviously a variable limit as between several ranges, and to avoid confusion, may better be called carrying capacity. A true saturation point occurs when a large number of widely separated optimum ranges exhibit the same carrying capacity.
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> It should be observed that while saturation point appears to be a property of a species, carrying capacity is a property of a unit of range.
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> Every range has, of course, a limit of carrying capacity. Not all species, however, exhibit a saturation point. The existence of a saturation point is not yet definitely proved in any species, although I am personally satisfied that it exists in bobwhite.[39]

Leopold documented different population dynamics in different species—some more stable, others highly variable—which suggested potentially different management strategies. "In hoofed animals there is so far no visible evidence of any density limit except the carrying capacity of the food."[40] A saturation point—if such a thing existed—could serve as a goal, beyond which no further manipulations were worthwhile, rather like the "original capacity" of the range scientists. If saturation points did not exist, however, then understanding the factors determining carrying capacity was the key to effective management. These factors not only varied in space and time; they were themselves affected by game populations. "[O]verstocking range with game birds carries no invariable penalty in loss of future carrying capacity, but overstocking range with browsing mammals does."[41] It is here that carrying capacity became a concept useful to hunting advocates: "The obvious lesson is not to let a good herd irrupt. To prevent an irruption this herd must be kept trimmed down to a safe margin, and the carrying capacity

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[39] Aldo Leopold, 1933. *Game Management*. New York: Charles Scribner Sons, pp.50-51.
[40] Leopold, *Game Management*, p.54.
[41] Quoted in Meine, p.369.

of the range built up so there is a safe margin of capacity above population."[42] Leopold's textbook helped launch game management on a radical new course, in which managers would treat wildlife "as a crop" that could be increased by careful observation and manipulation of environmental factors:

> Every range is more or less out of balance, in that some particular aspect of food or cover is deficient, and thus prevents the range from supporting the population which *the other aspects would be capable of supporting*. Management consists in detecting that deficiency and building it up. This once done, some *other* aspect will be found to be out of balance, and in need of building up. Thus, one move at a time, each skillfully chosen, does the manager attack the job of enhancing productivity.[43]

Leopold very nearly achieved a complete reworking of carrying capacity, from an ideal and static norm to an inductive and dynamic guide. Working with wildlife instead of livestock, he had more latitude to accept swings in animal populations, and the most vocal constituency he faced—hunters—were in support of culling in the event of overstocking. This may explain how he could arrive at an idea of carrying capacity that would take range scientists another three or four decades to recognize. Range scientists did not embrace Leopold's use of carrying capacity, however, and when they later came to similar conclusions they instead rejected the term outright. For their part, ecologists would shortly revert to an idealist, static (or at least equilibrium-based) and quantitative conception (see part 3). After all, if carrying capacity wasn't stable or normative, if it could not be calculated or made predictive, what did it signify any longer?

[42] Quoted in Meine, p.370.
[43] Leopold, *Game Management,* p.135 (emphases in original).

Even Leopold seems to have fallen back into a more conventional notion of carrying capacity at times. In a lecture prepared on the eve of World War II—and not published until long after his death—he pondered what ecology could teach about politics and war.

Every environment carries not only characteristic kinds of animals, but characteristic *numbers* of each. Thus the characteristic number of Indians in virgin America was small… Every animal in every land has its characteristic number. That number is the carrying capacity of that land for that species. When we arrived on the scene we raised the carrying capacity of the land for man by means of tools.[44]

He went on to venture some thoughts about human population "by analogy with animals":

One of the most emphatic lessons of ecology is that animal populations are usually self-limiting; that the mechanisms for limitation are diverse, even for a single species; and that they often shift inexplicably from one kind to another; that the usual sequence is for some limitation to act before the end of the current food supply is in sight.

Such mechanisms should be understood as "fixed attributes" of *populations*, he suggested, "probably as immutable as the color, form, and habits of the individual creature." War, then, might be such a self-limiting mechanism in humans:

[T]ools have actually raised carrying capacity, and ethics have at times suspended predation, but perhaps this is possible only within certain limits of population density. Perhaps the present world-revolution is the sign that we have exceeded that limit, or that we have approached it too rapidly. If so,… why not call a moratorium on human increase?[45]

Carrying capacity in Leopold's sense informed generations of wildlife managers as they worked to produce harvestable surpluses of game species on refuges and reserves. Manipulating habitats and populations to suit one another—by flooding, burning or cropping, controlling predators (both natural and human), relocating wild animals or releasing captive-bred animals—became the standard approach of state and federal

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[44] Ecology and Politics [1941]. *In* Susan L. Flader and J. Baird Callicott, eds. *The River of the Mother of God and Other Essays by Aldo Leopold*. University of Wisconsin Press, 1991, p.282
[45] Leopold, "Ecology and Politics," p.284.

wildlife agencies throughout the US, and it remains prevalent to this day. Carrying capacity thus became complicit in both the successes and the mistakes of twentieth century wildlife management: Stabilization or increase in the abundance and distribution of many species of fish and game were achieved, for example, but often at the expense of predators, native competitors, and genetic diversity. The approach could also be used to rationalize the wildlife impacts of large habitat alterations such as dams and irrigation projects through mitigation measures for a narrow range of target species.[46] The unintended consequences of past management efforts based on carrying capacity constitute some of the major challenges facing today's conservation biologists.

In both range and wildlife management, carrying capacity begged the question it was intended to address—that is, how many animals a given habitat could actually support *at a particular point in time*. This was the practical issue confronting managers, and simply using the term implied that such a number existed and could be determined. But what if the number varied over time?[47] Range scientists have found that many grasslands fail to exhibit stable carrying capacities for livestock, especially in drier and more variable climates. Others have reached similar conclusions for large areas of Africa, where efforts to impose stable stocking rates have frequently backfired both socially and ecologically.[48]

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[46] CHECK DUNLAP FOR FURTHER DETAILS.
[47] R.Y. Edwards and C.D. Fowle, 1955. The Concept of Carrying Capacity. *Twentieth North American Wildlife Conference*.
[48] Behnke, Scoones and Kerven, eds., 1993. *Range Ecology at Disequilibrium*.

3: Population Biology: Optimization and Dynamic Equilibrium

The two remaining uses of carrying capacity are both anticipated in Leopold's 1941 lecture. They emerged concurrently after World War II, with overlapping points of origin but widely divergent audiences and applications. One retained flora and fauna as its object but transferred the epistemological basis of carrying capacity from inductive and applied to deductive and theoretical.[49] The other shifted the object of the concept to humans and expanded its scale to continents and the entire globe, giving rise to the neo-Malthusian sense of carrying capacity that pervades general use of the term today (see part 4).

Leopold's notion of carrying capacity did not lend itself to theory-building or experimental replication. As a function of any particular habitat-population interaction, carrying capacity might be contingently determined and of only local or ephemeral significance, capable of yielding "skillfully chosen" steps to "build up" productivity at particular sites but of little use to academic ecologists. In his landmark 1953 textbook, *Fundamentals of Ecology,* Eugene Odum extricated carrying capacity from these difficulties by collapsing the very distinction that Leopold had viewed as definitive:

Populations characteristically increase in size in a sigmoid or S-shaped fashion. When a few individuals are introduced into, or enter, an unoccupied area population growth is

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[49] That Leopold derived his concepts inductively is evident in this passage from *Game Management* (p.54): "To sum up my own present opinion on the saturation point: the laws of chance cause a large variation in the carrying capacity of local ranges. The laws of chance must once in a while produce a range approaching optimum, even where there is no management. Such accidental optima ought to show correspondingly high densities. If external or environmental forces alone determined maximum density, the maxima occurring in a large number of samples in one state (or other large block) might be expected to run much higher or lower than in another. The fact that they do *not* run much higher or lower in bobwhite on its main range is evidence that some *internal* force or property, which is not subject to large variation as between regions, is also operative, and sets the upper limit beyond which wild populations do not increase."

slow at first…, then becomes very rapid, increasing in exponential or compound interest fashion…, and finally slows down as the environmental resistance increases…until a more or less equilibrium level is reached around which the population size fluctuates more or less irregularly according to the constancy or variability of the environment. The upper level beyond which no major increase can occur (assuming no major changes in environment) represents the upper *asymptote* of the S-shaped curve and has been aptly called the *"carrying capacity"* or the saturation level.[50]

Leopold had treated saturation points as a hypothetical possibility that awaited empirical verification (which had been achieved to his satisfaction for the bobwhite): if populations displayed the same maximum density across many different sites, then one could infer that the limit was a fixed attribute of the species. Odum asserted that such consistency had in fact "been observed again and again… regardless of whether one is dealing with fruit flies in a milk bottle or with fish in a new pond." The universality of the sigmoid curve rested not on multiple observations of the same species but on a handful of observations of multiple species. Moreover, it was derived not from the kind of field measurements that Leopold cited—"data on population growth of field populations," Odum conceded, were "few, incomplete, and hard to come by"—but instead from "laboratory studies of fruit flies, flour beetles, or other convenient organisms." Convenient here referred to suitability for reproduction and observation under artificially optimized environmental conditions of temperature, food, and so forth: in such settings, "a rather sharp and definite asymptote is reached with very little fluctuation, natality and mortality being balanced so long as new media are added continually to maintain a constant environment." Ideal and fixed environments revealed ideal, fixed carrying capacities.

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[50] Eugene P. Odum. *Fundamentals of Ecology* (first edition). W.B. Saunders Company, 1953, p.122 (emphases in original).

By a curious logic, carrying capacity could then appear as a property of organisms abstracted from any environment whatsoever (rather as with ships before). Odum characterized growth under laboratory conditions as the "intrinsic rate of natural increase" of organisms—the rate that would obtain in the absence of "environmental resistance." He then likened the lab situation to situations that could be observed in the field, especially if one looked at short-lived organisms (such as those used in lab experiments):

> The best opportunity to observe the fundamental growth form occurs when the population enters or is introduced into a new, unoccupied environment; this may occur every year or oftener in organisms with short life histories or only occasionally in other organisms.[51]

Or, perhaps, never in many others—most longer-lived species only rarely enter into such an environment, except on very small spatial scales (e.g., after wildfire, soil disturbance, or disease outbreaks). Odum also found the same S-shaped curve, however, among certain *introduced* animal species: sheep on Tasmania, pheasants on Protection Island, Washington, and starlings in the US. It was as though introductions—or invasions—were the standard of population growth in nature, against which actual observed cases should be evaluated.

The pattern similarity suggested a methodological turn of enormous significance: modeling population growth by translating the sigmoid curve into a mathematical equation. "Such curves very closely approach the logistic curve," a differential equation developed by Belgian mathematician Pierre-Francois Verhulst (1804-1849) to model human population growth. In the equation, *K* denoted "the maximum population size

[51] Odum, *Fundamentals of Ecology,* p.125.

possible, or 'upper asymptote'"—Odum's carrying capacity. Using such equations, Odum argued, one could infer "the environmental resistance created by the growing population itself, which brings about an increasing reduction in the potential reproduction rate as population size approaches the carrying capacity." This was what Leopold had called saturation points, but now it rested on very different grounds. Even though K could never be observed in the field, its mathematical existence permitted the development of models that could be elaborated and tested for single or multiple species. "Environmental resistance" referred to the disparity between field observations and mathematically derived ideals—it was a concept necessitated by, and defined in terms of, an ideal, static carrying capacity.

Odum's carrying capacity made it appear that the attributes of its predecessor concepts could be found in nature. The growth of a population in the wild could be indirectly calculated using models developed from findings produced in laboratories, where conditions resembled those of ship-building or engineering more generally: technical control of design, inputs, execution and observation. The deer and wolves of the Kaibab, for example, could be modeled as interacting populations that rose and fell in lagged synchronicity, exhibiting a dynamic equilibrium—that is, a fixed point around which actual numbers fluctuated. The models could be modified to reflect circumstances affecting a given site and species of interest, and the results could help both to make decisions about management and to advance research in the new field of population biology. Carrying capacity was now an attribute of a dynamic system rather than a ship, and it was equilibrial rather than static. But it was nonetheless predetermined by its conceptual derivation to be ideal, numerical, and basically stable.

Odum cautioned against mistaking his model for the reality it attempted to describe. Simply "fitting" Verhulst's differential equation was not, he acknowledged, sufficient grounds for treating the observed patterns as explained or predicted by mathematical means:

> It should now be emphasized that although the growth of a great variety of populations—representing microorganisms, plants, and animals—including both laboratory and natural populations, have been shown to follow the sigmoid pattern, it does not follow necessarily that such populations increase according to the logistic equation. There are many mathematical equations which will produce a sigmoid curve. Mere curve-fitting is to be avoided. One needs to have evidence that the factors in the equation are actually operating to control the population before an attempt is made to compare actual data with a theoretical curve.[52]

Odum also recognized that his concept of carrying capacity could be applied to humans, and it was in relation to global human population that the epistemological difficulties of his carrying capacity concept became unmanageable. "Population growth forms and upper asymptotes are of extreme interest in human demography," he wrote, citing a 1936 study that "fitted world population growth to a sigmoid curve." Based on the study, Odum predicted that

> the population of the world, now about 2,200 million, is in negative acceleration phase and should reach an upper asymptote of 2,645 million in the year 2700, *provided* the carrying capacity of the world for human beings is not increased by that time… To what extent the upper asymptote for man can be raised is a question being actively debated at present. Continued studies of the growth form of animal populations should help us to obtain an answer. In the meantime, one should not use the sigmoid curve to predict the maximum size of future populations of man or organisms *unless one is sure that the carrying capacity of the environment will remain largely unchanged during the interval*.[53]

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[52] Odum, *Fundamentals of Ecology,* pp.124-125.
[53] Odum, *Fundamentals of Ecology,* p.125 (second emphasis added).

The problem of distinguishing between organisms and environment as factors determining population growth was rendered intractable by the variability of environment itself, especially where humans were concerned. People might intentionally alter their environment—much as scientists manipulated conditions in laboratories—in ways that raised (or lowered) the asymptote toward which their population moved. Like Leopold, Odum here chose to retreat from a static notion of carrying capacity, notwithstanding his own earlier arguments in deriving *K*. Discussing the curve for starlings, he noted:

> Even if the exact numbers of starlings were known it is likely that actual points on the graph would deviate from the theoretical curve, because climatic fluctuations would likely cause temporary interruptions of population growth [and]…only a very approximate value could be determined for the upper asymptote. This would be generally true of natural populations; in fact, as already mentioned, many natural populations are never very far above or below the asymptote which itself changes from year to year as environment changes, thus making it difficult to distinguish between changes caused by environment and changes due to population growth. Nevertheless, a potential and characteristic growth form is inherent in the population and will express itself when for any reason the population is greatly reduced or the environment improved.[54]

After reviewing the starling and two other empirical examples—those of the introduced populations mentioned above—Odum conceded that "so far, ecologists have not been able to distinguish quantitatively" between environment and population as factors affecting growth.[55]

Odum turned this apparent difficulty into a virtue, however. Any observed downturn in the growth of a population in the wild could be interpreted as an instance of carrying capacity imposing its limits. Any decline followed by a rebound did not refute the universality of the sigmoid curve—rather, it signaled the initiation of a new period of growth that would again follow the sigmoid pattern. If the next downturn occurred at a

[54] Odum, *Fundamentals of Ecology,* p.129.
[55] Odum, *Fundamentals of Ecology,* p.130.

different population size than before, then the carrying capacity could be inferred to have changed; nonetheless, and by the same logic, internal checks on population could still be said to exist, even though they never expressed themselves independently from environment. The *shape* of the curve signified an organism's "intrinsic rate of increase," even if the gross value of the asymptote changed over time.

Taken together, these arguments suggested that carrying capacity is always fluctuating, including for reasons we don't understand and thus cannot model. Repeated testing and refining of models might lessen this gap in particular cases, but the overall theory was by this point self-validating. As Zimmerer observes, the postulate of generalized carrying capacity assumed an idealized growth curve and spatial homogeneity, but neither assumption stands up to empirical scrutiny. "The assumption of a 'continuing steady-state basis' embedded in the definition of carrying capacity is simply unwarranted."[56] If one sees a Petri dish as an environment, then by analogy one can see the world's ecosystems as capable of supporting a certain number of organisms—but only by assuming perfect linearity across vast scales of time and space. Environmental resistance and carrying capacity were defined tautologically; they were in fact the same concept viewed from opposite ends of an underlying—and entirely idealist—dualism of "nature" and organisms.

A final irony warrants mention, since it links Odum's carrying capacity with its antecedent use in relation to livestock grazing. "[I]n arid areas," he remarked in passing,

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[56] Karl S. Zimmerer, 1994. Human geography and the "new ecology": the prospect and promise of integration. *Annals of the Association of American Geographers* 84, p.XXX.

"rainfall is the chief limiting factor determining the amount of grass and thereby the number of sheep that can profitably be raised in any particular year."[57] This is exactly the point that more recent critics of conventional range management have made to support their contention that no such thing as an ideal, static, numerical carrying capacity exists in many rangeland settings: Abiotic factors that are unpredictable and therefore effectively random (from a modeler's perspective) may override biotic interactions in determining population size at any given place and time.[58] Odum, it seems, recognized the factual support for their point but not the point itself.

4: Global human (over)population

Carrying capacity, as Odum formulated it, expressed with precision what could be expected if a population lived *without relation to its environment*. This could never occur empirically, of course, but knowledge of such a norm nonetheless allowed every observed deviation from it to appear as an *actual* shortage of some environmental resource. In this way Odum gave scientific expression to the so-called "principle of population" made famous by Malthus some 150 years earlier. Glacken sees its origins in the much older principle of plenitude: that life, by its (God-given) nature, is given to exuberant self-reproduction. The contradiction between this plenitude and the limitations of "environment" drove Malthus's argument, both substantively and rhetorically: Life, in the absence of environmental constraints, would rapidly overpopulate the earth (and, he claimed, the rest of the universe). The fact that it has not yet done so served as

[57] Odum, *Fundamentals of Ecology,* p.134.
[58] Behnke, Scoones and Kerven, eds., *Range Ecology at Disequilibrium.*

incontrovertible evidence that life is "checked" by limitations (whether misery or vice), and that the principle is therefore empirically true. Every empirical instance of misery and vice thus appears, conversely, as an instance of such checks, and the growing population—if only by bringing larger numbers of victims into the path of every check—appears as the root of the problem.

As we have seen, however, Odum did not advocate such a notion of carrying capacity, and his arguments left open the possibility—at least in theory—that humans might increase their carrying capacity indefinitely. Rather, the final type of carrying capacity arose elsewhere, in popular attempts by ecologists to raise awareness of environmental problems. It differs in scale, audience, and application from the type that Odum helped establish in population biology. By now, neo-Malthusian arguments are familiar enough to require little description, and voluminous enough to defy any comprehensive treatment here. I seek only to establish the moment and source of its emergence and its continuity from that time to the present.

The neo-Malthusian use of carrying capacity appears to have its origins in the book *Road to Survival,* by ecologist and ornithologist William Vogt. Published in 1948 for a popular audience, *Road to Survival* captured a strain of fatalistic pessimism born of the horrors of World War II, even as it extended an American apocalyptic narrative form earlier realized in terms of soil erosion and the collapse of ancient civilizations.[59] Vogt's first job out of college had been curator of a bird sanctuary; he went on to edit *Bird Lore* and

[59] Several of Vogt's opening (fictionalized) anecdotes concern soil erosion. For an antecedent that does not employ carrying capacity, see Paul Sears, *Deserts on the March* (Norman: University of Oklahoma Press, 1935).

Audubon's *Birds of America*. *Road to Survival* sought to persuade its readers that "we all live in one world in an ecological—and environmental—sense," and that the earth should be understood on the model of a sanctuary or preserve. Later, he became president of Planned Parenthood.

Vogt defined carrying capacity[60] using a "bio-equation": "C = B: E," in which C stood for carrying capacity, B for biotic potential, and E for environmental resistance. Biotic potential, Vogt wrote, had "an absolute or *theoretical* ceiling that is never reached, except under extraordinary conditions," and "a very large number of *practical* ceilings," which were "in most of the world dropping lower every year… The practical ceiling is imposed by the *environmental resistance,* which is the sum of varying but always great numbers of limiting factors acting upon the biotic potential." The parallels with Odum's theory are striking, and it should be evident from the preceding section that Vogt's "equation" was tautologous: Environmental resistance only existed by positing a theoretical limit that was itself derived from carrying capacity, and from which empirical reality necessarily deviated.

Vogt conceded that "the equation finds complicated expression in terms of civilized existence." But he insisted on its reality and its importance, and he applied it to vastly larger scales than had been attempted in range or wildlife management or in academic biology:

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[60] Vogt corresponded with Leopold after 1941 and nearly went to Wisconsin to study with him (C. Meine, personal communication).

> The equation is, perhaps, oversimplified, but it expresses certain relationships—almost universally ignored—that every minute of every day touch the life of every man, woman and child on the face of the globe.
>
> Until an understanding of these relationships on a world scale enters into the thinking of free men everywhere, and into the thinking of rulers of men who are not free, there is no possibility of any considerable improvement of the lot of the human race. Indeed, if we continue to ignore these relationships, there is little probability that mankind can long escape the searing downpour of war's death from the skies.
>
> And when this comes, in the judgment of some of the best informed authorities, it is probable that at least three-quarters of the human race will be wiped out.[61]

Like Malthus, Vogt tended to reduce the environment to arable land and food production, and he evaluated the carrying capacity of every continent in the world except North America and Antarctica—all but these two, he concluded, were already overpopulated. The result was a schizophrenic message: the ecological imperative that "man…must live within his means" meant, in practice, that carrying capacity must be increased by reducing environmental resistance through measures such as irrigation and insect control.[62] Protecting the environment and increasing productivity appeared as harmonious—even identical—goals, united by the concept of carrying capacity.

With ecology and wealth thus wedded together, Vogt could propound a political agenda that was at once environmentally deterministic and geo-politically timely. In his foreward, he asserted that America's prosperity rested solely on its "lush bountifulness," which was so great that it had more than compensated for sustained environmental abuse. Not only must we Americans learn to steward our natural resources more wisely, we must also, "in human decency as well as in self-protection, use our resources to help less well-endowed peoples."[63] He chose for his frontispiece a bar graph of "living standards"

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[61] William Vogt, 1948. *Road to Survival*. New York: William Sloane Associates, pp.16-17.
[62] Vogt, *Road to Survival,* p.22.
[63] Vogt, *Road to Survival,* p. xiv.

in 34 countries, measured in weekly wages per worker; the graph was adapted from "*Global War,* An Atlas of World Strategy." It was a logical next step to see a direct trade-off between wealth and population size: "When the carrying capacity of the land rises, the possibility of higher living standards increases for limited numbers of people, or a lower living standard for excessive numbers."[64]

Vogt's arguments can be traced with remarkable detail through the work of subsequent neo-Malthusian ecologists such as Garrett Hardin and Paul Ehrlich. Both Vogt and Hardin employ the range science sense of carrying capacity to illustrate their larger arguments, equating the world with a pasture that can only support a finite number of animals/humans; for both, the logical prescription is basically the same as the one Leopold reached regarding deer: don't let the herd irrupt. Ehrlich, like Vogt and Hardin, uses carrying capacity to conclude that the irruption has already occurred:

> The key to understanding overpopulation is not population density but the numbers of people in an area relative to its resources and the capacity of the environment to sustain human activities; that is, to the area's *carrying capacity*. When is an area overpopulated? When its population can't be maintained without rapidly depleting nonrenewable resources (or converting renewable resources into nonrenewable ones) and without degrading the capacity of the environment to support the population. In short, if the long-term carrying capacity of an area is clearly being degraded by its current human occupants, that area is overpopulated.
>
> *By this standard, the entire planet and virtually every nation is already vastly overpopulated.*[65]

Through the work of neo-Malthusian ecologists, the two post-WWII uses of carrying capacity have blurred into one another, the more "scientific" lending academic credibility and the more popular providing political traction and hyperbole. Carrying capacity has

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[64] Vogt, *Road to Survival,* pp.22-23.
[65] Paul R. Ehrlich and Anne H. Ehrlich, 1990. *The Population Explosion*. New York: Simon and Schuster, pp.38-39 (emphasis in original).

helped induce them—along with countless others, including prominent scientists from many disciplines—to fall into the same conceptual trap that Malthus set more than 200 years ago with his principle of population: a theory that is self-fulfilling and irrefutable by means of empirical evidence, even as it claims empirical support from a wide range of sources and fields. (No wonder it appears so scientifically and theoretically elegant!) The major difference is that the neo-Malthusians have fallen into the trap a century and a half or more later, as though unaware of the criticisms that decimated Malthus's arguments in his own time—arguments that compelled him to rewrite the book six times. (It is worth noting that the second edition is the most widely read today.) I submit that carrying capacity—a concept that did not exist when Malthus wrote his *Essay* and which acquired its scientific credibility between 1890 and 1950—was a major decoy in luring so many people into this trap. Not that it went entirely unrecognized as such, however: When the fourth use of carrying capacity first appeared in *Science,* in a 1955 article entitled "Ecology and the Population Problem," it was placed in scare-quotes, as if the author recognized he was using the term in an unusual, perhaps inappropriate way.[66]

Conclusion

Except in its earliest, literal sense, carrying capacity has been plagued with serious conceptual flaws due to the contrasting but frequently conflated characteristics of its various uses. Should carrying capacity be understood as a fixed quantity (like the tonnage of a ship) or as a dynamic one (such as the amount of grass in a pasture)? Is it ideal, or

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[66] A.M. Woodbury, 1955. Ecology and the Population Problem. *Science* 122: 831-834.

real? Is it a function of human technology and adaptation, or of natural processes beyond human control? Finally, can something discerned at very small, bounded scales—in a Petri dish or a ship, a pasture or a pipeline—be applied at much larger scales without a crippling distortion of meaning? Its shortcomings have been noted by critics in several fields, but the links between these fields have eluded attention, and the origins of its flaws have thus been overlooked.

Three conclusions emerge from analysis of the genesis and history of carrying capacity. First, it has had an extraordinary affinity with state policies and administration. Determining an ideal, fixed and quantitative measure of how much *X* a given *Y* should (be able to) convey, support or produce is, it appears, an abiding aspiration for government agencies in areas as varied as taxation, resource management, planning, transportation, communications and conservation. That it has worked in certain applications—generally at small spatial and temporal scales, and in things or systems that are well understood and readily controlled—has ratified its use in other areas where control was desired but elusive. Even where carrying capacities have proved illusory, they have provided an appearance of objectivity, rationality and precision to policies that might otherwise have been revealed as politically or economically motivated.

Second, the history of carrying capacity sheds light on the "discursive" dimension of environmental politics. The concept has migrated through many different contexts, capitalizing on the familiarity and authority of its earlier uses while apparently foreclosing scrutiny of whether the new application was appropriate or coherent. It is as though the continuity of the term itself, aided by its intuitive sensibleness—who cannot understand the idea that one's capacity to carry something has a measurable and stable limit?—has enabled its potency and persistence as it moved from one field to another. Moreover, by appearing to refer to actual relations in the world, rather than ideal constructions, carrying capacity has benefited from a kind of linguistic Pandora's box: Once one has used the term, one has tacitly affirmed that its referent exists, even if determining its values in a given case is a complex and difficult matter.

Third, the uses of carrying capacity have generally increased in spatial scale since the term emerged in the first half of the nineteenth century: from ships, to rivers and pastures, to states and continents, to the globe as a whole. Extension from one field to another has entailed expansion to larger and larger areas or systems, and the mistakes and problems created by the term—whether of a practical or an ethical nature—have grown correspondingly. Carrying capacity thus suggests the power of the presumption that "scientific" concepts—in this case represented by attributes of idealism, stasis and numerical expression—are scale-independent. That a concept works at a small scale, such as a Petri dish, does not guarantee that it will work at much larger ones, howsoever scientific it may appear.