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Volume Author/Editor: Lance E. Davis, Robert E. Gallman, and Karin Gleiter

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Chapter Author: Lance E. Davis, Robert E. Gallman, Karin Gleiter

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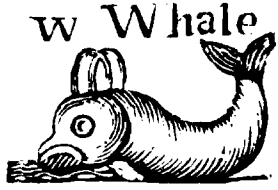
4 Natural Resources



The American whaling industry reached a peak of activity in the early 1850s; hunting waned slightly as the decade wore on and declined precipitately after 1860 (see table 1.2). The story of the rise and fall of the industry is told in detail in chapters 12 and 13, and chapter 9 analyses the role of demand shifts during the period of contraction. Although changes in demand are usually accorded the leading role in the story of the industry's demise, three supply-side factors also appear in standard accounts: (1) the quality of American whaling crews deteriorated, (2) the costs of whaling vessels rose, and (3) overhunting depleted the stocks of whales. These factors are supposed to have shifted the whaling supply schedule to the left, which, ceteris paribus, should have forced the industry to contract. Chapter 5 considers the first factor, chapter 6, the second, and this chapter, the third.[1]

Many students of the subject have concluded that one reason the American whale fisheries declined was that whales became scarce.[2] Their evidence, however, has been either incomplete or indirect. There have been careful studies of individual whale groups, as well as attempts to infer changes in whale stocks from shifts in whaling productivity or from the complaints of unsuccessful whaling captains. There has been no comprehensive effort to consider the scale of nineteenth-century hunting in the context of preexisting populations and potential levels of reproduction. This chapter is intended to make good the deficiency. That is, it brings together fairly comprehensive estimates of the numbers of hunted whales toward the beginning of the nineteenth century, cal-

1. Crew quality and whale stocks are also treated in chapter 8, and other aspects of supply are discussed in chapters 7, 10, and 11.

2. See Hohman 1928, 290, 297–300; Bockstoce and Botkin 1983, 107–41; Burton 1983, 132–34; Shuster 1972, 345–57; Maran 1974; Spears [1876] 1926, xviii; Dulles 1933, 221; Nordhoff 1895, 161–62.

culates potential levels of net reproduction, compares these figures with the rates of nineteenth-century hunting, and reaches conclusions about depletion.

The impact of depletion (if there was depletion) on the industry would have been a function not only of the diminution of whale populations, but also of the sensitivity of whaling productivity to diminished numbers. Productivity could have been affected long before populations became endangered. It is also possible that hunting led to shifts in the behavior of whales that reduced their reproductive abilities or made them warier and more difficult to capture. Any of these developments, if it took place, would have acted to reduce whaling productivity. The course of productivity change is considered in chapter 8. The present chapter is concerned exclusively with the issue of depletion. There is one overarching question: were whale populations hunted down far enough by the late 1850s to make it likely that American whaling contracted for lack of whales?

Marine biologists have learned a considerable amount about the feeding habits, migration patterns, social organization, mating customs, fertility levels, and mortality rates of the principal groups of hunted whales. Also, since whales have come to be recognized as endangered species, much effort has gone into attempts to estimate the effects of hunting and the capacity of whale stocks to recover from overhunting. In part such work rests on direct observation; in part it is a result of theoretical model building. For example, California gray whales, a group that was protected at an early date and that has successfully recovered from overhunting, have been the subject of intense observation.[3] Again, the demography of particular groups of whales has been modeled.[4] These models have made it possible to predict the rate at which whale stocks would increase in the absence of hunting, the forces that would bring growth in a given group to a halt, and the level and structure of the population that would lead to the maximum sustainable yield—the largest number (or weight) of whales of a given type that could be taken each year without reducing the stock. This yield occurs at the population level and structure that produce the maximum positive difference between births and deaths (or, alternatively, between the rate of additions to the ranks of adults and the death rate of adults), and it depends upon the abundance of food, that is, the feed/whale ratio.[5]

In general the models assume that, since the whale has almost no natural enemies other than human beings, the size of a given population in the absence

3. "Locally, the gray whale became the subject of protection in California a few years later [after the turn of the century] and of total protection under the Washington Convention of 1946" (Tønnessen and Johnsen 1982, 113). For an example of the observation of the gray whale, see Rice and Wolman 1971.

4. See, for example, the treatment of the sperm-whale model in Frost 1979, 19–21, 73–74, and appendix 8. See also Gambell 1976.

5. The maximum sustainable yield models—as planning devices—have been subject to severe criticism. For example, "simulation testing of the NMP [new management procedure] revealed that populations managed under the NMP were quite likely to be exterminated" (*Dolphins, Por-*

of hunting will depend on the available feed: krill for baleen whales (e.g., right whales, bowheads, grays, and humpbacks), and squid for toothed whales (e.g., sperm whales). Mammalogists believe that the adjustment process—in which the population expands when extra feed is present and ceases to expand when feed is being appropriately exploited—turns on the age of sexual maturity. They think that the age of sexual maturity falls when feed is abundant and rises when it is scarce.[6] It should be said that not all of the parameter estimates are firmly based. There is also little or no direct evidence of the characteristics of the stationary population. Life expectancy in the absence of hunting is not well established; the impacts of hunting on fertility are not known with certainty (Frost 1979, 65–73).

With these reservations the demographic models may be used to estimate, on the basis of supplies of krill and squid, the levels of whale populations that existed before humans hunted on a large scale.[7] Presumably supplies of food for whales have varied from time to time, but, as Allen points out,

> [whales] would be less susceptible to such changes [in food supplies, due to climatic changes] than many animals . . . . whales have a much longer life cycle than nearly all fish, and their reproductive pattern, with an average of less than one young per year, obviously does not provide the flexibility required to produce the major changes in strength of cohorts which can occur with fish. Compared with terrestrial mammals, whales would seem to be living in a much more stable environment, which is not subject to drastic climatic changes such as droughts, that may occur on land. (Allen 1980, 20)

In any case, population estimates of the whales hunted by Americans have been made for the period preceding the rise of American whaling. They differ a good deal from one to another, but there is enough consensus to permit a series of useful conclusions to be drawn. For four sets of these estimates, see table 4.1.

4.1 Did American Whalemen Damage Sperm-Whale Populations?

The data on sperm-whale stocks are particularly complete; they omit only the North Atlantic populations, and those were small. The "original" sperm-whale stock (total population, exclusive of the North Atlantic) can be set at between 1,800,000 (Scarff) and 2,400,000 (Frost, Allen). Six hundred thousand is a wide range, but not remarkably wide, given the problems of estimation.

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poises, and Whales 1991, 13). For our purposes, however, maximum-sustainable-yield models are a useful place to begin.

6. The decline in the age of sexual maturity can be pronounced. It is believed that this age for minke whales fell from fourteen to six years, when the twentieth-century slaughter of Antarctic whales raised the krill/whale ratio so pronouncedly. See Wiley 1985, 42, 44, 46.

7. The relationships among different types of whales competing for the same food are a complicating factor. For example, the population of sei whales apparently increased when the fin and blue whales were first hunted. See Gaskin 1982, 319.

Table 4.1 **Estimated Whale Stocks before the Advent of Intensive American Hunting (thousands)**

Stock	Scarff[a]	Frost[b]	Allen[c]	Bockstoce/ Botkin
Southern Hemisphere				
Right	30–40+	100+[d]	(100+)	—
Humpback	100–150	100[d]	130	—
Sperm	1,168	578[d]	1,250	—
North Pacific and Western Arctic				
Bowhead	10–20?	25+	20	30
Other right	unknown	unknown	(20)	—
Gray	11–12	15	(20+)	—
Humpback	unknown	unknown	13	—
Sperm	612	580[d]	1,150	—
North Atlantic				
Bowhead	10?	7	n.a.	—
Other right	unknown	unknown	n.a.	—
Gray	not present	unknown	n.a.	—
Humpback	4+?	1–2[d]	n.a.	—
Sperm	unknown	unknown	n.a.	—
Total[e]				
Bowhead	20–30	32	20	30
Other right	30–40+	100[d]	120+	—
Gray	11–12	15	20+	—
Humpback	104–54	101–2[d]	143	—
Sperm	1,780	1,158	2,400	—

Sources: Scarff 1977, 332; Frost 1979, 266–67; Allen 1980, 19; Bockstoce and Botkin 1983.

Note: According to Scarff (1977, 332) and Allen (1980, 19) the size of the total population is typically about twice the size of the exploitable population.

[a]Question marks used in the source, presumably to show uncertainty.

[b]The bowheads listed under "North Pacific" are in fact whales living in the Bering Strait and the Sea of Okhotsk. The grays refer to the eastern Pacific stock only. The bowheads listed under "North Atlantic" are those in Davis Strait and Hudson Bay only. The humpbacks listed under "North Atlantic" are the western Atlantic stock only. Three components of Frost's estimates refer not to the period before the advent of intensive hunting but to later dates: (1) sperm whales in one of his five divisions of the Southern Hemisphere are estimated as of 1946; (2) sperm whales in the western division of the Pacific are estimated as of 1910; (3) bowheads in the North Pacific are estimated as of 1850. The original stocks in all three cases were almost certainly larger than the figures in the table.

[c]Parentheses used in the source presumably show uncertainty.

[d]These are estimates of exploitable stocks (i.e., mature animals) only.

[e]Several of the totals are incomplete.

Even the lower figure—1,800,000—is very large relative to the number of sperm whales killed in the nineteenth century. According to Charles Scammon, during the period of most intensive American whaling (1835–72), Americans caught about 147,000 sperm whales and killed but lost another 15,000. Scammon bases his estimates on two assumptions, (1) that the average whale taken

yielded twenty-five barrels of oil, and (2) that many whales were harpooned, escaped the hunters, but subsequently died from their wounds. Scammon estimated that the second group (those that escaped but subsequently died) were equal in number to about 10 percent of the first group (those that were captured), and that they were also of the same average size. Given these assumptions and an enumeration of the barrels of sperm oil brought back by whalemen, he can—and does—estimate the total number of sperm whales killed.[8]

Twenty-five barrels may be too low an appraisal of the average yield from a sperm whale. Estimates ranging upward to forty-five barrels have appeared in the literature. The firmest set of figures—Best's—covers the period 1816–29 through 1900–1925, and indicates that the sperm whales taken by American ships and barks (a sample comprising 735 voyages) averaged 33.6 barrels of oil. Applying this value to the oil output data (see table 9B.1), and assuming with Scammon that whales killed but lost amounted to about 10 percent of those captured, one obtains an estimate of 177,000 sperm whales destroyed by Americans in the years 1805 through 1900. Americans probably accounted for about three-quarters of the sperm whales taken in this period.[9] The total number killed by all whaling fleets would have been about 236,000. Substituting Scammon's average yield of twenty-five barrels would raise the number to 331,000; adopting Stevenson's equally well founded average-yield estimate of forty-five barrels (1904, 187, 192) would lower it to 184,000. That is, whalemen appear to have killed, in total, between 8 and 18 percent of the initial stock, in a harvest distributed across ninety-six years. Even the largest single-year American catch, that of 1837 (between 3,760 whales at forty-five barrels per whale and 6,770 at twenty-five barrels) was considerably less than 0.5 percent of the initial stock, and only a small fraction of the maximum sustainable yield that lay within the procreative capacity of sperm whales.[10] Modern levels of sperm-whale populations also suggest that damage by nineteenth-century whaling was not disastrous. For example, estimates in Frost's monograph

8. Scammon [1874] 1968, 244. Scammon's estimate and those we have substituted for it (see below) ignore certain elements of the catch. Since Scammon and we base our estimates on oil landed, we leave out of account the whales represented by oil lost during the voyage due to leakage, oil sold during the voyage or shipped home in advance (to the extent such oil was not counted as oil landed), and oil that went down with vessels that were sunk. (See Best 1983, 42–43.) The loss rate for New Bedford vessels (sperm whalers, baleen whalers, and nonspecialists) was 6.3 percent, but presumably the average vessel lost had less than an average catch, since it sank before completing its voyage. Oil sold overseas amounted to little (Best 1983, 42). Advance shipments of oil were not uncommon, but these shipments were recorded in the catch data. How much leakage accounted for, we do not know. At a guess the catch estimate in the text may be as much as 10 percent short, for the above reasons.

9. Best 1983, 45, 46. According to Best the United States accounted for 77 percent of the total output of the United States, Great Britain, and the British colonies. The production of all other whaling nations was negligible. The figures for Britain and its colonies are likely to be too low.

10. This level of procreation was probably never achieved, since the sperm-whale population never fell far enough below the carrying capacity of the food supply to set off those forces that would have raised fertility to its maximum level. See Frost 1979, 256–60.

(1979, 266–67) show that sperm whales numbered more than 850,000 in the late 1970s. They have survived both the American assault of the nineteenth century and the much more formidable assaults of the twentieth.

Sperm whales are distributed across the Atlantic, Pacific, and Indian Oceans. If whalemen concentrated on individual hunting grounds until stocks there were depleted, and only then moved on to other grounds, even the limited catch described above might damage the capacity of certain sperm-whale groups to reproduce. Two sets of data—both fairly small—suggest that this may have happened in the Western Indian Ocean and in the Sea of Japan, but the evidence is ambiguous and may indicate, not that whales became less numerous, but that they became more wary (Wray and Martin 1983, 226; Bannister, Taylor, and Sutherland 1983, 248–52). In any case there is reason to believe that a scarcity of sperm whales—if it existed at all—did not affect the fishery as a whole. Peter Best's study (1983, 46) shows no time trend in the average oil yield per sperm whale captured by American ships and barks, and also none for those captured by schooners and brigs, from 1816–29 through 1900–1925. If the population had been placed under pressure, the average yield would surely have fallen, if only because the density/fertility mechanism would have come into play. That is, the feed/whale ratio would have increased, the age of maturation would have fallen, births would have increased, and, because of the increase in the proportion of young whales, the average age and average size of the population would have declined, and the average age and average size of the sperms captured would have declined also.

There are other reasons to believe that individual hunting grounds were not depleted on a large scale. Sperm whales are polygynous. A heterosexual pod—a group traveling together—typically consists of a bull and ten or fifteen cows and their young, including some full-grown but socially immature bulls (not yet competitive with the patriarch). Two or three mature bulls usually trail the pod at a safe distance, waiting to take over the cows when the patriarch dies or becomes disabled. All other mature bulls have been driven away by the patriarch and travel alone or in male pods. The patriarch-dominated pod is formed during the breeding season. After servicing the cows the patriarch leaves, and the pod is matriarchal until the next season. Between breeding seasons patriarchs travel alone. Pods of socially immature, but physically mature, males travel together, occasionally with socially mature bulls who have yet to win harems.[11]

A very large fraction of the whales in the male pods, the trailing bulls, and the males traveling alone could be taken without adversely affecting the reproductive power of the population. Indeed, successful hunting of these males might actually raise the reproductive power of the group, by raising the feed/

11. Frost 1979, 19–21, and appendix 8. See also Harrison Matthews 1978, chap. 8, especially 165–66; Burton 1983, 76.

whale ratio and thus lowering the age of sexual maturity.[12] Since mature male sperm whales are three or four times as large as females, they would have been preferred by hunters. Having chanced on a heterosexual pod, the hunters would choose—if they had a choice—to take the males first. As long as they did not leave the pod utterly bereft of socially mature males, its reproductive power would be left undisturbed. In any case, if all the socially mature bulls attached to the pod were killed, the cows would recruit a new patriarch in the next, or perhaps even (less likely) the same, breeding season.[13]

There is persuasive evidence that nineteenth-century hunters did take disproportionately large numbers of mature bulls. Wray and Martin have gathered the records of nineteen sperm-whaling vessels over the years 1800–1887. The records provide various bits of information about captured whales: for thirteen the size or sex alone, for ninety-eight the yield in oil (Wray and Martin 1983, 236–39). The yield information is particularly useful. Mature cows and bulls are of very different average sizes, cows weighing only 30 percent as much as bulls (Leatherwood and Reeves 1983, 82). Since yield was an increasing function of weight, a full-grown cow must have yielded about 25 percent as much oil as a full-grown bull. The largest bulls in the Wray and Martin sample—two or three only—are one-hundred-barrel whales. From those observations one may infer that full-grown cows in this population (Western Indian Ocean) rarely exceeded twenty-five barrels. Now, of the 111 whales for which size, sex, or yield information is available, 42 percent seem clearly to have been bulls; that is, they were designated as "bulls" or as "large," or they yielded more than twenty-five barrels of oil. Another 10 percent were twenty-five-barrel animals; some may have been females, but some also must have been males. Moreover, of those below twenty-five barrels, many must also have been bulls. After all, nursery pods—the only groups from which cows could be taken—would have contained roughly equal numbers of immature males and immature females.

Be that as it may, the first datum recorded above—that 42 percent of the sperm whales taken were large bulls—is all that is needed to establish that hunters preferred to kill the largest animals available to them. If sperm whales had been taken at random from the total population, roughly one-half of those captured would have been immature, another one-quarter mature females, and

12. That would be the case if the captured bulls were within the normal migration routes of the nursery pods. Bulls often leave these precincts and travel far north or south to squid-rich, but cow-poor, waters. Since those areas are off the nursery migration routes, taking such bulls would not have a direct and immediate effect on the food supplies of the nursery pods. It is also possible that the sexual activity of the patriarch is stimulated by the presence of potentially competitive bulls. If too many of the bulls trailing the pod were killed, its reproduction rate might drop.

13. Harrison Matthews 1978, chap. 8. See Friends of the Earth 1978, 153. Two contradictory positions need to be recognized: (1) cows were easier to kill than bulls, which might have induced hunters to concentrate on them; (2) whalemen might have simply taken the first whales they reached, so that their catches might approximate random samples of the groups of whales they attacked. But see the text below, and Gambell 1983, 15.

only about one-quarter mature males. Since at least 42 percent of the whales killed were large bulls, it is reasonable to conclude that whalemen sought out the largest whales they could find, and it is equally reasonable to suppose that they did not interfere with reproduction in an important way.[14]

Thus, given the total number killed, it seems highly unlikely that even concentrated hunting would have depleted the stocks of sperm whales or greatly eroded their reproductive power. In any case the evidence indicates that hunting did not follow a pattern of local concentration. As American whaling expanded, hunters very quickly moved into the South Atlantic, and around Cape Horn and the Cape of Good Hope into the Pacific and Indian Oceans, and then into the Sea of Japan and the far North Pacific. The fact that whalemen continued to hunt in all grounds supports the argument that one ground was not hunted out before whalemen moved on to another.

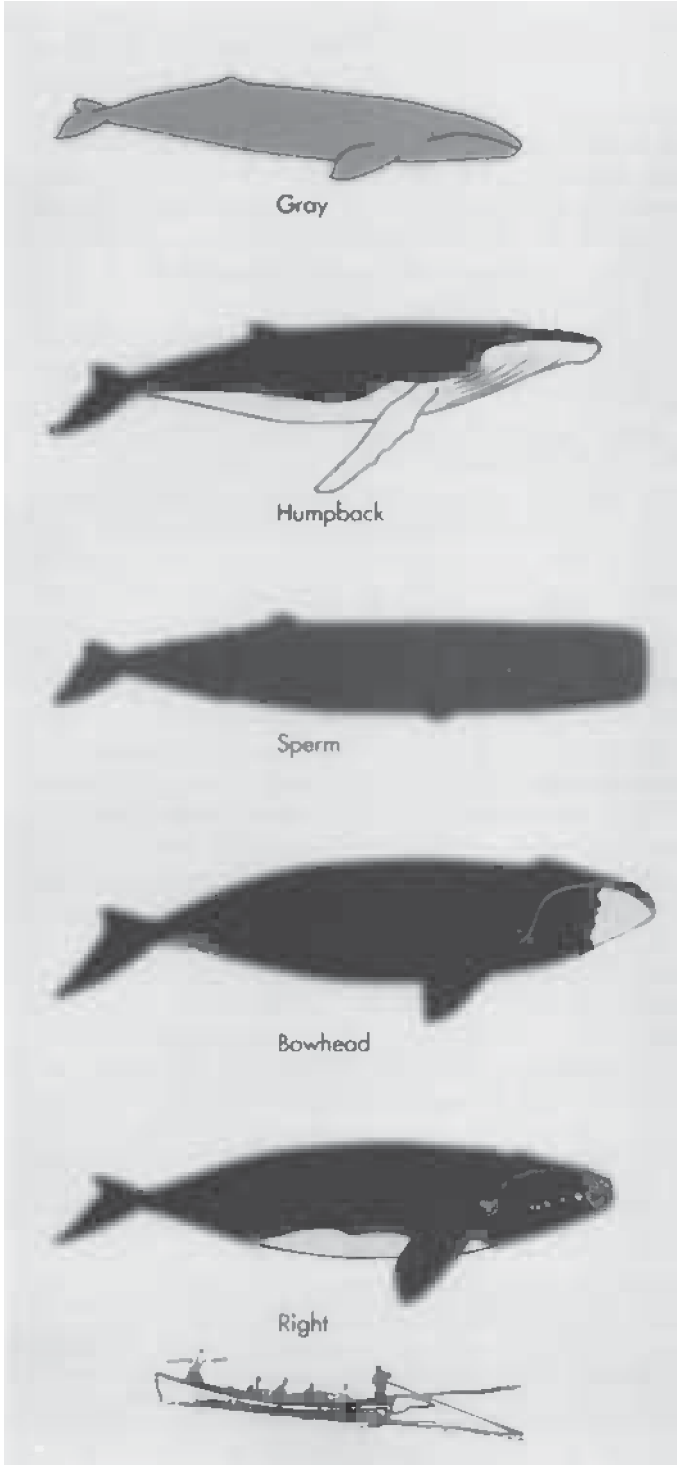
4.2 Did American Whalemen Damage Baleen-Whale Populations?

Quantitative evidence on the baleens hunted in the nineteenth century is less complete and reliable than that on sperm whales. Frost has data by sex and narrow geographic region for sperm whales; comparable information is not available for baleens. There are estimates of the total stock of baleens (exclusive of those in certain grounds). As to the various types of baleens, there is good information on the numbers of bowheads in each of the following grounds: Davis Strait, Hudson Bay, Bering Strait, and the Sea of Okhotsk. The same is true of the gray whales off the coast of California. There is only incomplete information on the geographic distribution of rights and humpbacks.

By all accounts baleens were much less numerous than sperms. Taking Frost's evidence, adding Allen's data for North Pacific humpbacks and rights, substituting Bockstoce and Botkin's figure for bowheads of the Western Arctic, and using Scarff's and Allen's procedures to adjust the exploitable stock estimates to total population levels, it is possible to form a reasonable estimate of the size of the original population of the hunted baleens. The figure produced by this procedure is something in excess of 367,000 (compared with between 1,800,000 and 2,400,000 sperms).[15]

14. The data cited in the text are from Wray and Martin 1983, 236–39. Best's work more or less confirms the reasoning of the text. He identifies a few cows that yielded more than twenty-five barrels, but his research was not confined to the hunting ground studied by Wray and Martin, the Western Indian Ocean (Best 1983, 52). According to Wray and Martin, the Indian Ocean sperm-whale population consisted of relatively small whales. That yield was an increasing function of weight may be inferred from Best's table 8. If the fifty-five-foot whales in that table were hundred-barrel whales, and if the thirty-foot whales were of a size equivalent to mature cows, then the table allows one to infer that mature cows averaged twenty-five barrels. In fact, the whales described in the table are mainly bulls; cows are said to be more slender than bulls. Consequently, the twenty-five barrel average is probably an upper bound on the true average value. Dropping the limit to twenty barrels would raise the share of large bulls in the total of all sperm whales to 56 percent.

15. According to Scarff (1977, 332) the ratio of the total population of baleens to the exploitable population is 1.5 to 1.0. Allen (1980, 19) puts the ratio at 1.3 to 1.0 for humpbacks.



These whales that Americans hunted in the nineteenth century are drawn to scale. Their adult lengths range from forty to forty-five feet for a male gray whale (females are a little longer) to sixty feet for a male sperm whale (females are much shorter). The standard American whaleboat was about twenty-eight feet long, two feet deep, and six feet wide.

Scammon estimates the number of baleens killed in the years 1835–72 at 131,000; once again, his figure needs to be adjusted. According to Scammon, the average baleen whale yielded about sixty barrels of oil. If Stevenson's average is used instead of Scammon's, and if one assumes that different groups of whales were taken in proportion to their numbers, an average figure of sixty-four barrels is obtained. Since humpbacks were less widely hunted than the other baleens, even this figure is probably too low. If it is assumed that they were taken only one-third as often as their numbers would predict, then the average baleen yielded seventy-three barrels.

Scammon ([1874] 1968, 244) also estimates that whalemen killed and lost one-fifth as many baleens as they caught, a proportion that seems too high. According to Bockstoce and Botkin (1983, 116) bowheads killed and lost came to fewer than 15 percent of those caught. Since loss rates were particularly high for bowheads, and since a bowhead lost by one whaler was not infrequently recovered by another, a loss rate of 10 percent for all baleens seems more reasonable. If these revised assumptions are correct, it appears that whalemen of all nations killed about 180,000 baleens in the nineteenth century.[16] Even this figure is likely to be a little too high, since it rests on output data that combine the oil taken from blackfish and walruses with that taken from baleen whales.

On the one hand, given the initial stocks and the numbers caught, it seems that baleen populations were more likely to have been depleted than were sperm-whale populations. There are two other facts that suggest the same conclusion: baleens are monogamous and may even form permanent sexual attachments; the female baleen is larger than the male. The natural factors that helped protect the reproductive capacity of sperm whales from the depredations of hunters—the small relative size of the female, polygyny, and the easy substitution of one male for another in the breeding season—are absent among baleens.

On the other hand, the reproductive capacity of baleens is much greater than that of sperm whales. According to Frost (1979, 19, 257) the pregnancy rate of adult sperm cows is about 0.19 per year (that is, about 19 percent are pregnant each year), when the population is stable, and can rise to as much as 0.25. Baleen cows calve about every two years—a pregnancy rate of 0.50.[17] Except

16. Stevenson 1904, 192. The text statements rest on the assumption that the American fishery was responsible for three-quarters of the catch.

17. Gaskin 1982, 309; Slijper 1979, 389–90. Fin whales bear every other year, blues every two to three years, humpbacks four years out of five. Grays bear at least every other year and perhaps annually, according to Slijper. Rice and Wolman (1971, 117) find a fertility rate for adult females of 0.46 per year, which roughly confirms Slijper's judgment.

There is much less information on rights and bowheads, but Frost's statement (1979, 19) appears to cover them: "All baleen whales give birth and breed in the warmer waters within their range. In larger species this generally occurs every other year." Slijper says (384–85) that the gestation period for bowheads (Greenland whales) is nine to ten months, and that the lactation period for both bowheads and rights is twelve months. Gaskin (1972, 88), however, puts the gestation period of the right whale at eleven to twelve months and the lactation period at five to six months.

for gray whales, who are bothered by killer whales, baleens have no more trouble with natural predators than do sperms.[18] Rice and Wolman (1971, 118) have shown that the California gray whales, in the period in which they were protected from hunting, maintained a rate of natural increase of about 5 percent per year.[19]

Whale populations adjust to the available feed. If populations are reduced by hunting, the age of sexual maturity falls, the birthrate goes up, and hunting losses are replaced, so long as they are not too large. The extent of the rise in the rate of natural increase depends on the disproportion between food supplies and existing whale stocks. In the case of baleens the natural increase—expressed in absolute numbers—is thought to rise, as the population is hunted down, until the population has been reduced to about 60 percent of its maximum size. If the population is driven below that level, the natural increase (again expressed in absolute numbers) is believed to fall, and eventually the whole population will be put in serious jeopardy.[20]

In the early nineteenth century there were at least 367,000 baleen whales. If they are treated as one population—a procedure that is not legitimate except for illustrative purposes—a population of about 220,200 (367,000 × .60) would have maximized the natural increase. That is, only if the population had been reduced by about 147,000 whales in a relatively short period of time would the maximum natural increase (the maximum sustainable yield) have

All of these figures are roughly consistent with the delivery of a calf every other year. *Dolphins, Porpoises, and Whales* (1991) suggests longer birth intervals for rights (a pregnancy rate of 0.24 to 0.30 [361]) and bowheads (a pregnancy rate of 0.15 to 0.27 [346–47]).

Biological information on whales is most complete for species that have been recently hunted, because many specimens were available to researchers and because strong efforts were made to enumerate these groups regularly. Of the populations that have not been hunted recently, scholars have the best information on the California gray whale, because the grays are particularly easy to observe. They calve in few shallow-water areas off the coast of California, and their migration route is within sight of land. Thus their activities are relatively easily monitored, and they are also easily enumerated. Bowheads and rights are more difficult to observe and, since neither group is hunted extensively today, biologists have few specimens with which to work.

18. Henderson 1972, 36. But see Burns 1919, 237–38, which contains an account of orcas attacking a bowhead. Rice and Wolman (1971, 98–99) present evidence that orcas attack gray whales frequently, but rarely with success.

19. A birthrate of 0.13 and a death rate of 0.08—yielding a net rate of increase of 0.05—are given. Elsewhere, however, Rice and Wolman (1971, 131) treat the figure of 0.08 as an estimate of the death rate for adults and indicate that the death rate for immature whales "is more likely to be greater than that of adults" (117). Since they view the rate of 0.08 as an upwardly biased estimate of the adult death rate, it seems improbable that the computed rate of natural increase was much less than 0.05 per year. A second set of population growth rates, based on total population estimates, indicates that the gray-whale population grew at about 11 percent per year from 1952–53 (shortly after the grays were protected) to 1959–60 (112–13). "Trends from 1960 to 1967 are uncertain" (131).

20. Frost 1979, 70. It should be said that Frost hedges his account with the most cautious language. See also Matthiessen 1995, 70, which suggests that right-whale stocks fell much lower than the posited 60 percent, yet have begun to recover; and Rice and Wolman 1971, 91. Discussing baleens, Scarff (1977, 337) says, "A whale stock at between 30–70% of its initial population level will exhibit a maximum net recruitment rate . . . of only 5–7% annually." See also Lien and Merdsoy 1979, 46–49.

been reached. In fact, only 180,000 baleens were killed over the entire century. If Rice and Wolman's findings concerning the rate of natural increase of gray whales are representative of baleen whales in general, the maximum sustainable yield would have been about 11,010 per year (220,200 × .05). That is, even if the baleen population had been driven as low as 220,200, whalemen could have taken as many as 11,010 each year, without jeopardizing the population. In fact, American whalemen never took as many as 7,000 in a year; in most years they took only a small fraction of that number.

Can the Rice and Wolman results be regarded as representative of baleens as a whole? Allen (1974, 356–57) warns against extrapolating from one species to another, but he makes the point in the context of a discussion of overhunted groups. He points out that the gray whale may have recovered quickly because it employs only a limited number of breeding grounds; even when the grays had dropped to a small fraction of their original number, population density on the breeding ground was always high enough to ensure successful breeding on a large scale. He points out that other groups, such as rights, might not be able to recover so quickly. Scarff (1977, 337) puts the maximum recruitment rate (additions to the stock of adults minus deaths of adults) of baleens at 5 to 7 percent, which roughly squares with Rice and Wolman's findings, and Rice (1974, 189) estimates that the maximum sustainable yield from bowheads was as high as the 5 percent recorded for grays.

This chapter is concerned not with the issue of recovery from severe overhunting, but with the maximum sustainable yield, a level that is reached long before whale populations are put in danger. In this context it seems safe enough to accept a maximum sustainable yield rate of 5 percent for all baleens. The question is not recovery, but breeding habits under normal conditions.

The calculations discussed to this point have treated all baleens hunted by the American nineteenth-century fleet as though they were alike, as though they bred indiscriminately across groups, and as though they were hunted in the same indiscriminate way. These conditions were not met, of course; it is necessary to look at individual groups separately.

California gray whales represent something of a special case, although their peculiarities were shared, in some measure, with humpbacks.[21] They produced inferior oil and bone and relatively small average amounts of either (about thirty-five barrels of oil per whale). Initially they were not easily taken. Whalemen called them devilfish because they attacked the whaleboats. Until about midcentury they were hunted in the North Pacific by whalemen primarily seeking rights and bowheads but willing to take grays, if the opportunity presented itself. Relatively few were killed.

Gray-whale hunting changed when the calving grounds in the bays of the Baja Peninsula were discovered. Whalemen then began hunting grays in the winter, chiefly as an off-season activity, when the pursuit of rights and bow-

21. Much of what follows is drawn from Henderson 1972.

heads in the north was impossible. Previously they had shifted out of the northern grounds in winter and sailed to the New Zealand, Chilean, or California grounds to hunt sperm whales and humpbacks. After the mid-1840s gray whaling became another off-season option—a risky one, at first, but when hunters had learned to enter the bays successfully and had adopted the Greener gun (a weapon that allowed them to remain at a safer distance from their ferocious prey), gray whaling became an important activity. According to Henderson, the number of gray whales killed on both the northern and calving grounds rose from a total of seven to eight hundred over the years 1846–54 to seven times that number over the next decade, but by 1866–74 the figure had fallen to just over two thousand. At that point, whalemen effectively gave up hunting gray whales. The total number killed by Americans in the nineteenth century thus came to about eighty-two hundred (Henderson 1972, 256–57).

According to the most reliable estimates (see the figures given by Frost and Allen, table 4.1) the California herd originally numbered between fifteen and twenty thousand. (Scammon [1874] 1968, 23, implies that it was nearer fifty thousand—a figure modern students of the subject discount.) Following the line of argument adopted previously, eighty-two hundred whales taken from an original population of fifteen to twenty thousand ought not to have destroyed the gray-whale herds, but gray whaling was a special case. Hunting was extremely concentrated in space and time. The gray-whaling era lasted only about thirty years; once the calving grounds were entered, virtually all of the whales killed and listed in Henderson's tally were females. The ability of the stock to reproduce was directly attacked. Many of the females were pregnant or left behind calves too young to feed themselves. Almost all of those calves starved to death, and they—as well as those attacked and killed by whalemen to draw the mothers within harpoon range—are missing from Henderson's totals.

The slaughter, then, was much greater than Henderson's figures describe, and it is a wonder that the California gray-whale population survived at all. It did, however, and today is as large as it ever was.[22] Probably the increased cost of capture due to diminished numbers, together with weakening markets for oil—especially the inferior oil yielded by the grays—led whalemen to abandon the California grounds in time to save the remnants of the population. In any case the American whale fleet did not end its days for lack of gray whales. The grays, a species that probably accounted for less than 6 percent of all whale oil in any year, were simply never central to American whaling.

The bowheads of the Western Arctic are a second group of baleen whales for which there are good population data. According to Bockstoce and Botkin they originally numbered between twenty and forty thousand, in all likelihood about thirty thousand (see table 4.1). They were first hunted commercially in

22. The California gray was taken off the endangered species list on 15 June 1994 (*News and Observer* [Raleigh, NC] 16 June 1994).

1848. Pelagic whalers took about 18,700, or something more than 60 percent of the original population, before World War I. Again, the slaughter was concentrated in a relatively short period of time. It was not, as in the case of the grays, a destruction visited chiefly on females, but by 1915 the population is said to have been reduced to about three thousand.

In an attempt to reconcile their estimates of the original stock, the number killed by pelagic whaling, and the number remaining in 1915, Bockstoce and Botkin have simulated the bowhead population under a variety of parametric specifications. They have been able to achieve a reconciliation only on the assumption that mortality from all sources other than whaling exceeded recruitment, an assumption that initially seems implausible. The recruitment and survivorship ratios, however, represent values influenced by hunting. Bockstoce and Botkin argue that one bowhead feeding ground after another was hunted out, and the whales were forced to withdraw into always more limited feeding grounds (1983, 137; but see Tillman, Breiwick, and Chapman 1983, 145; Breiwick and Mitchell 1983, 150–51). In these circumstances hunting would not set off a favorable density/fertility mechanism leading to more births, since the relevant feed/whale ratios would not rise. Even so, it is more than a little puzzling that deaths—apart from whaling deaths—exceeded births. Perhaps hunting interfered in some other way with procreation, although we know of no argument or evidence to that effect. In any case bowheads, with their relatively confined feeding grounds, were probably in greater danger of extermination than were rights, sperms, or humpbacks (Slijper 1979, 395).

Whatever the mechanism, the evidence suggests that the bowhead population had been reduced to about three thousand by 1915. Even so, neither the conclusion that the final collapse of the bowhead population occurred while U.S. whaling was still otherwise viable, nor the conclusion that the collapse contributed importantly to the end of U.S. whaling, is obvious. The fleet was declining before the Civil War, dramatically so after the mid-1870s, when bowheads must still have been relatively numerous. The estimates of kill per unit of effort assembled by Bockstoce and Botkin are highly variable but exhibit no clear downward trend before the 1880s. The index of total factor productivity of New Bedford whalers in the Western Arctic (discussed in chapter 8) shows no unequivocal long-term drop before the early 1880s (see figure 4.1). At this point there were practically no New Bedford whalers left in the Western Arctic. These two indexes cannot provide conclusive evidence of changes in the stock of whales, since they are influenced by factors other than the availability of whales.[23] Nevertheless, it is highly unlikely that developments pro-

23. Bockstoce and Botkin 1983, 130, 131. Among the developments almost certainly having an important effect on productivity were a deterioration in the quality of seamen on whalers and various technical improvements, such as the darting gun and the steam-powered whaler (the latter influencing the Bockstoce and Botkin estimates, but not the Davis, Gallman, and Gleiter figures,

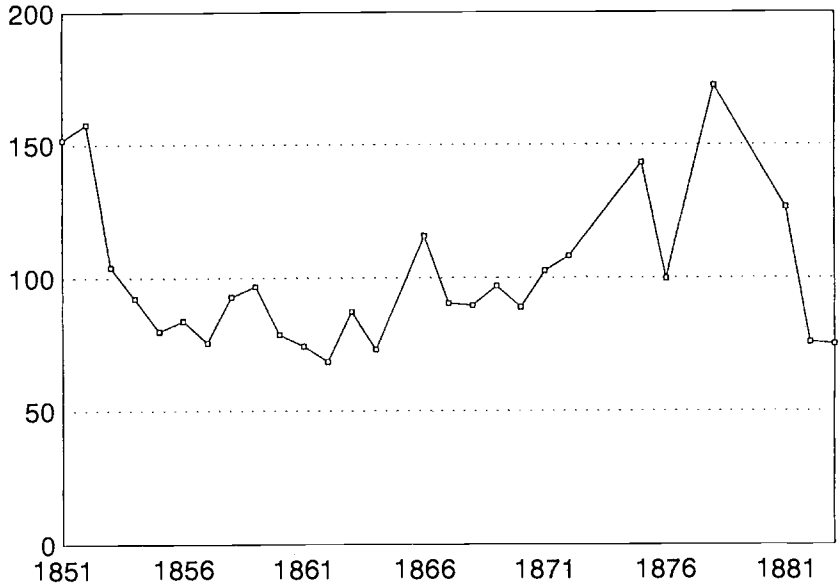


Fig. 4.1 Index of total factor productivity, New Bedford whaling vessels hunting the Western Arctic, voyages ending 1851–83 (base = average 1851–83 = 100)

Note: See chapter 8 for a description of the productivity index.

moting improved productivity would have been powerful enough to offset the effects of a drastic reduction in the stock of bowheads, had one taken place. In any case, if the American fleet had been forced to contract because of sharply rising costs associated with the depletion of the bowhead population, the kill-per-unit-of-effort and total-factor-productivity indexes would both have fallen. Given that neither index shows a marked downward trend, at least until 1880, it is doubtful that New Bedford owners, agents, and seamen were driven out of whaling by a shortage of bowheads.

Data on the remaining groups of baleens hunted in the nineteenth century are much less complete. It is known that humpbacks were actively sought, if

which cover only sailing vessels). The decline in labor quality tended to reduce productivity; improved technology tended to raise it. The Bockstoce and Botkin average weighted kill-per-unit-of-effort indexes are 1849–59, .179; 1860–69, .147; 1870–79, .111; 1880–89, .159; 1890–99, .083. Dropping 1849 and 1850 reduces the average for the first period (now 1851–59) to .120. See chapter 8 for an extended analysis of these issues.

Conrad (1989, 974–87, especially 984–85) disagrees with Bockstoce and Botkin. According to him the original population ran between fourteen and twenty thousand. By 1914 the figure had fallen to about thirty-four hundred but had risen back to about seventy-eight hundred by the end of the 1980s. Our interpretation of the connections between the number of bowheads and the decline in the whaling fleet would be unaffected by our adoption of this account.

less so than other whales—they had characteristics that made them less desirable than most.[24] Their oil and bone were less valuable than those of rights, and each whale yielded smaller amounts of both. For example, humpbacks averaged only 55 barrels of oil, compared to perhaps 100–120 barrels for rights. Humpbacks were also difficult to catch; they are fast and agile and have long flippers which, in the death throes of the whale, sometimes smashed whaleboats. Unlike right whales they sank when killed. When this happened in shallow water—which is where the humpback was typically hunted—the whale could be raised, or marked and picked up later, when natural causes forced the carcass to the surface. (In this case, of course, the carcass might be eaten by sharks.) In deep water, humpbacks could be neither successfully raised nor marked, but whalemen seem to have been able to keep them afloat by holding them on lines run to the whaleboats.[25]

Since humpbacks have been heavily hunted in the twentieth century, there is no question that they survived the nineteenth in large numbers.[26] How many were killed in the nineteenth century is by no means certain. The estimate of the average size of baleens, discussed above, rests on the assumption that humpbacks were taken only one-third as often as their relative numbers would lead one to expect, but that assumption is a guess, no more. A guess of some kind is required, however, if we are to get an idea of the extent to which the remaining baleens—chiefly rights—were under assault. Assuming that the guess is correct, it is possible to make the following computation:

Total number of baleens killed:		180,000
Of which:		
bowheads of the Western Arctic	18,700	
California grays	8,200	
humpbacks, perhaps	35,000	
Total of the three above:		61,900
Leaving rights, Atlantic bowheads, Japanese and Korean grays, blackfish, and the odd fin or sulphurbottom		118,100

The original stocks of rights and Atlantic bowheads amounted to about 177,000. About 70,800 could have been taken before these populations were reduced to the level of the maximum sustainable yield. Once the two populations (combined) reached that level, perhaps 5,000 animals could be taken each year without jeopardizing the stocks. In no year did American whalemen take as many as 7,000 baleens, a figure that includes, of course, Western Arctic

24. For accounts of humpbacking, see Dulles 1933, chap. 20; Nordhoff 1895, chap. 10; Ashley 1938, 65. According to Dulles, it was common for New London whalers to spend two summers and a winter at Desolation Island, hunting rights and humpbacks.

25. Ferguson 1936, 130–31, 145–48. The accounts on these pages apparently refer to humpbacking in deep water.

26. According to Mitchell and Reeves (1983, 160–61), 4,053 humpbacks were killed in the western North Atlantic (including Iceland) in the forty-one years 1850 to 1890, and 4,810 from 1891 to 1931.

bowheads, humpbacks, and grays, as well as rights and Atlantic bowheads. Moreover, the 118,100 figure is a residual, and it is based in part on oil taken from animals other than rights and Atlantic bowheads: Japanese and Korean grays, fins (a few), blues (a few), walruses (many), blackfish (many).

By the 1930s right whales had become so scarce that the whaling nations, fearing the rights would be exterminated, agreed to protect them from all hunting.[27] Since data on twentieth-century hunting of rights are fragmentary, it is not clear whether the scarcity was a legacy of the period of American whaling, or a product of late nineteenth- or early twentieth-century Norwegian hunting.[28] The absence of reported kills implies that twentieth-century hunting was not intense. After all, if right populations had been hunted down in the twentieth century, would there not be abundant data on the number killed? Not necessarily. Hunting records of the twentieth century, particularly those reporting distributions among baleen groups, were not well kept before the 1930s. It is likely that rights were mistakenly counted with the more numerous rorquals. One must also take into account inaccuracies in the records. Peter Matthiessen (1995, 70) reports that Russian whalemen secretly killed thousands of protected whales, including many rights: "A single Soviet ship . . . killed twelve hundred right whales in the single season of 1961–62."

For what it's worth, the rorquals survived—in the case of the blues, just barely—a much more savage assault in the twentieth century than that to which the baleens hunted by the Americans were subjected in the nineteenth. Between 1904 and 1978, 331,000 blue whales and 692,000 fin whales were taken in the Antarctic grounds alone (Tønnessen and Johnsen 1982, 751). The original populations of blues and fins in the entire Southern Hemisphere amounted to 270,000 and 607,000, respectively. That is, over a seventy-four-year period the numbers of these whales taken substantially exceeded the original populations. Both groups were damaged, but they were not driven to extinction. By 1978 Southern Hemisphere blues probably numbered only 7,000–8,000 and fins 130,000. A much smaller fraction of the original population of rights was killed by nineteenth-century hunters, and hunting was spread over almost a century (Frost 1979, 266–67).

Right whales have characteristics that may have brought them more readily to the brink of extinction. Their numbers were never large. They were scattered over wide reaches of the oceans and were divided into at least three independent population groups; breeding probably did not take place across these groups. Concentrated hunting could have lowered population densities enough to interfere with breeding. The slaughter of the rights may have opened the way for the expansion of populations of whales that were not at that time being

27. Frost 1979, 31; Tønnessen and Johnsen 1982, 399–400. But Matthiessen (1995, 70) dates effective control to 1949.

28. Tønnessen and Johnsen 1982, 736, 751. "The main exploitation [of rights] was ended by the 1920s, although even at the end of this era right whales were more valued by whalers than blue whales" (*Dolphins, Porpoises, and Whales* 1991, 354).

heavily hunted—the fin whales, for example. The only way for the right populations to recover from hunting would have been through a rise in fertility, due to a fall in the age of sexual maturity, the fall in turn caused by an improved feed/whale ratio. If the fins expanded into the space left by the rights, the feed/fertility mechanism of the rights would not operate, at least not with full effect. As a result the calculations of the maximum sustainable yield described above may be too optimistic. Even so, the data do not suggest that the right-whale stocks had declined so far by the 1870s that a scarcity of whales served as a major check to the American whaling industry.[29]

4.3 Conclusions

Most of the evidence indicates that the stocks of sperm whales and humpbacks were decidedly not running out. The number of sperm whales killed in the nineteenth century is very small in comparison to the previously existing stocks and their procreative abilities. The same can be said of humpbacks. The picture with respect to rights, grays, and bowheads is less clear. Hunting was certainly a heavier burden to these populations, but it was probably not so heavy as to make them generally scarce by the time the American whaling fleet began its steep decline. This is not to say that they were undamaged by the American whaling fleet. The grays and bowheads were certainly hurt, and the rights may have been. It is only to say that the decline of American whaling antedated serious problems of whale numbers.

Supply-side pressures that would have led the whaling industry to contract may have emerged even in the absence of ecological disasters. Hunting may have affected the numbers and behavior of whales, even in cases where there is little evidence of overhunting. It may also have reduced population densities of some whales (even if the harvest never exceeded the maximum sustainable yield), making them less accessible and their capture more costly. Such reductions could explain the persistent search for new hunting grounds, even when the old ones had not been hunted out. Perhaps more likely, the whales may have become wary. William Scoresby ([1820] 1969, 172–73, 183) claims, for example, that when, in the seventeenth century, the Spitsbergen grounds were first opened, whales were so curious and unfearful that they "allowed themselves to be . . . closely approached" by the whaleboats, but in time they became timid. The same sequence was observed in the nineteenth century in Davis Strait and the Western Arctic.[30] As whales learned about men, hunting costs may have risen.

29. If a scarcity of baleens caused the decline of the fleet, the real price of whale oil should have been rising. It did rise, peaking in the period 1851–65, but, during the period of marked decline of the fleet after 1865, the real price fell. See table 9.11.

30. Bockstoce and Botkin 1983, 118–19; Wray and Martin 1983, 226; Lien and Merdsoy 1979, 48. Biologist Haven Wiley, of the University of North Carolina at Chapel Hill, writes (letter of 12 December 1986): "Ecologists interested in predation worry a lot about whether prey *densities*

Chapters 8 and 10 subject the total-factor-productivity index described in chapter 1 to analysis in an effort to explain differences in productivity over time. The impact of whale stocks on productivity is considered there in detail. The analysis of the present chapter suggests a hypothesis that will be tested: American whaling did not decline because of a shortage of whales.

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correlate with prey *availability* and clearly they often do not. With specific reference to whales, it is perhaps important to consider whether increasing wariness by the whales might have had a significant impact on their availability to whalers in sailing vessels."