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Spatial Dynamics of American Offshore Whaling in the 19th Century: Were sperm whales depleted?

In the late 18th and 19th centuries American, British and French offshore whalers extended their reach from the North Atlantic and into almost all parts of the world's oceans. While the British and the French had withdrawn from the offshore whale fishery by the middle of the 19th century, the Americans remained engaged in a fishery that continued but slowly declined for another 75 years. The causes of the British and French withdrawal and of the American decline have been much discussed, especially the role of depletion of the whales themselves. Two recent global analyses are relevant to this question. Whitehead (2002, hereafter Whitehead) considered how the abundance of sperm whales might have changed and Davis *et al.* (1997, hereafter Davis *et al.*) studied changes in the economic productivity of the American fishery. Whitehead suggested that 19th century whaling did not have major effects on sperm whale numbers, and Davis *et al.* concluded that the decline in American offshore whaling in the 19th century was not caused by a decline in abundance of either sperm whales or baleen whales prior to the late 1850s. Both Whitehead and Davis *et al.* considered the problem of how to reconcile their findings with the evidence of declines over the first half of the 19th century in the rate at which whalers encountered sperm whales in the Pacific (Bannister *et al.* 1981; Hope and Whitehead 1991). However, their analytical approaches precluded full incorporation of the complex, rapidly changing geography of whaling over the course of the offshore fishery, from its expansion into the Indian and Pacific Oceans in the late 18th century to its shrinkage back into the Atlantic Ocean in the late 19th century.

For the past several years, we have been extracting, compiling and analyzing data from whaling logbooks in order to describe the spatial distribution of 19th century American whaling. These data suggest, contrary to both Davis *et al.* and Whitehead, that the abundance of sperm whales declined markedly and rapidly in at least the Pacific Ocean in the first half of the 19th century. We argue that measures of economic productivity, such as those used by Davis *et al.*, that do not account for regional changes in whaling effort and whale availability are unlikely to capture the complexity of changes in 19th century whaling, and hence these measures of productivity alone cannot be expected to explain the industry's decline. Similarly, because whales in different regions often constitute separate populations, analyses of trends at a global scale, such as that presented for the sperm whale by Whitehead, are unlikely to reflect local or regional patterns for such populations and thus cannot be expected to convey the true biological significance of whaling.

Global Analyses by Davis *et al.* and Whitehead

The argument of Davis *et al.* hinges entirely on data from the port of New Bedford, Massachusetts, from which somewhat less than half of all 19th century American whaling voyages originated. Those authors developed a novel index of voyage productivity using aggregate information for all voyages, most of which were away from New Bedford for more than one year and many of which were away for up to four or five years. Their index was based on the difference between the value of the products from these voyages – sperm oil, whale oil and baleen – and the cost of producing them, especially the

cost of purchasing and outfitting the vessels and the cost of labor. Davis *et al.* made no attempt to examine data for individual voyages, e.g., in terms of the whaling grounds that were visited. Therefore, they did not explicitly account for the geography of whaling beyond the statements of destinations given to port authorities at the beginning of the voyages (e.g., Atlantic, North Atlantic, Pacific, Arctic).

Overall, the Davis *et al.* index of voyage productivity showed a decline across the first half of the 19th century followed by a leveling-off. To determine the effects of changes in whale abundance on whaling productivity, they computed their index separately for large ocean regions based on the stated voyage destinations, and regressed those indexes on estimates of previous whale catches (that they assembled from various sources) for those same large regions. They expected that the regression coefficients would be negative if the abundance of whales had a significant effect on voyage productivity. These coefficients proved to be either positive or, if negative, sensitive to alternate formulations of the analyses, leading Davis *et al.* to conclude (p. 312):

It does not seem probable that hunting pressures contributed in an important way to the decline in productivity and the eventual demise of the whaling fleet. . . . There is no support to be drawn from this regression for the assertion that whaling productivity fell as a consequence of overhunting.

Specifically with regard to sperm whales, they concluded that “Americans made no serious inroads into sperm-whales” (p. 516).

In contrast, Whitehead used global estimates of annual sperm whale catches in the 19th and 20th centuries, without regard to how or where the whales were taken, together with global estimates of current sperm whale abundance. The abundance estimates were derived from the correlation between estimates of present-day primary production as measured by surface chlorophyll and the distribution and abundance of sperm whales based on recent sightings surveys. Whitehead developed sperm whale population trajectories using several alternate models, including one of extreme population subdivision, concluding that “the open-boat hunt did not have a very substantial effect on the global population” (p. 302). Indeed, he suggested that the population was only reduced by 29% of its pre-whaling abundance.

Regional Analyses of Whales and Whaling

However, both Davis *et al.* and Whitehead noted inconsistencies between their global analyses and some regional studies of the effects of whalers on sperm whales. Thus, Wray and Martin (1983) assembled anecdotal evidence suggesting declines in sperm whale abundance in the western Indian Ocean. Bannister *et al.* (1981) demonstrated a substantial decline in rates of whaler encounters with sperm whales in the North Pacific between 1820 and 1870. Hope and Whitehead (1991) also documented a decline in encounter rates in the equatorial Pacific as whaling proceeded there. If the declines in the rates of encounters with sperm whales reflected declines in numbers of whales, these studies would be inconsistent with Davis *et al.*'s and Whitehead's global analyses. Both Davis *et al.* and Whitehead, however, argued that this was not the case, suggesting that the declines in encounter rates were more likely due to changes in whale behaviour in response to whaling.

In addition to the regional studies mentioned by Davis *et al.* and Whitehead, Clark (1887) described the abandonment of whaling grounds. He constructed a chart of whaling grounds based on published accounts and interviews of whalers in which he showed many grounds as having been “abandoned” by whalers, in whole or in part, by the 1880s. He concluded (Clark 1887, page 7) that “Many of the

grounds where vessels were formerly very successful are now entirely abandoned and others are but seldom visited.” Bannister *et al.* (2008) further documented this changing pattern of use of sperm whaling grounds over the 19th century, noting especially the timing of their abandonment.

Bannister *et al.* (1981) illustrated the timing of the abandonment of one ground that Clark showed as having been abandoned, the Japan Ground. This ground stretched between 30°N and 40°N latitude for roughly 70° of longitude between the Hawaiian (roughly 150°W) and the Bonin Islands (roughly 130°E), and whaling began there early in the 19th century. Bannister *et al.*'s plots of vessel location on days when whales were tried out (their Figure 5), show an increase in whaling east of 150°W in the 1830s and a decrease in activity east of 180° in the 1840s and no activity there in the 1850s. These authors also demonstrated a five-fold decline over the first half of the 19th century in the rates at which sperm whales were encountered and caught in this whaling ground, using several different definitions of encounter rates. Hope and Whitehead (1991) showed similar declines in sperm whale encounter rates around the Galápagos Islands over roughly the same period.

Several hypotheses in addition to declining abundance have been identified to explain abandonment of grounds and declines in encounter rates, primarily invoking the idea that whales changed behaviour in response to being hunted. One hypothesis is that the whales learned to be more wary and hence harder to encounter or to capture, or both. Another is that the whales learned to change their spatial distribution to avoid the whalers altogether. In addition, differential movement patterns of different segments of the population have been documented (Rendell and Whitehead 2003) that could result in a decrease in encounter rates independent of reductions in abundance.

Smith *et al.* (2008) tested some of these hypotheses. They showed that the declines in encounter rates on the Japan Ground were not the result of whales simply moving to the northern or southern periphery of that ground, although they could not test the possibility of the whales moving to substantially different areas where the whalers did not find them. Further, they showed that whales did not become more difficult to capture once sighted, although they could not test if they became less likely to be sighted. They also rejected the hypothesis that observed differences in movement patterns could have caused substantial declines in encounter rates, using data from Rendell and Whitehead (2003).

Two behavior-based possibilities remain to explain the declines in encounter rates found in regional studies: (1) sperm whales became more difficult to sight on the same grounds, and (2) sperm whales moved undetected to new areas. Below we examine additional information on the rates at which whalers encountered whales using data from 19th century logbooks, and in the process discuss the plausibility of behavioural change versus decreasing abundance as explanations for declining encounter rates.

American Voyage and Logbook Data

US-registered whaling vessels made roughly 15,000 voyages over the course of the fishery, and summary information on them has been compiled in several sources, beginning with Starbuck (1878) and then Hegarty (1959), and more recently Lund (2001) and Lund *et al.* (2008). We used the data in this last study to describe American whaling, including information on sperm and baleen whale products landed, voyage length, and announced whaling destinations. Following Davis *et al.*, we computed an index of whaling productivity for each voyage as the average of the landings of sperm oil, baleen whale oil, and baleen from different types of voyages divided by the number of days away from home port and multiplied by the value of these three products (dollars/barrel, Davis *et al.* 1997, p. 368-375). We examined the pattern of change of this index of productivity and compared it to Davis *et al.*'s

index.

We also used daily vessel position and whale sightings data extracted from voyage logbooks that were kept routinely on board American whaling vessels. These logbooks have been used occasionally for scientific purposes, beginning with Maury's (1852) whale charts (maps) showing the distribution of whaling activity and sightings by month and 5° 'squares' of latitude and longitude for the first half of the 19th century. We have assembled Maury's extant raw data from 556 voyages, consisting of daily vessel locations and days on which one or more whales were encountered (including groups of whales that were only sighted, those where a whale was also struck with a harpoon, and finally those that were caught and brought on board). We combined Maury's data with similar data that we extracted directly from 178 additional logbooks, and we supplemented those two data sets with the somewhat simpler data from the extant raw data for 703 voyages from Townsend (1935). Townsend's data set consisted of vessel locations on days on which one or more whales were captured. We charted (mapped) these data for different periods over the 19th century to show the changing spatial distribution of whaling vessels and whale encounters.

We also computed a simple encounter rate as the number of days on which one or more sperm whale were encountered divided by the number of days at sea. For this calculation we used the data described above, but omitting that data collected by Townsend (1935) because he only recorded whales caught, and omitting data from voyages that departed from other than New Bedford, MA, and nearby ports, in order to be more comparable with Davis *et al.* We also omitted voyages using mechanically powered vessels, to minimize the effects of changes in technology in later years. We computed our encounter rates for each year as the total number of days on which sperm whales were encountered divided by the total number of days whalers were at sea. We computed this ratio separately for voyages that whaled in the Pacific or whaled in the Atlantic, pooled the estimates over pairs of adjacent years, and computed sample standard errors based on the variability of the days with encounters. We examined these encounter rates by plotting them over time for each ocean area.

Voyage Productivity

The average value (in dollars) of the landings per day's absence from home port for American offshore whaling voyages declined from about 1830 through the middle of the century (Figure 1). The decline was similar to the change in the Davis *et al.* index of productivity, also shown in Figure 1, although the rate of decline of their index at mid-century was somewhat less than that of ours. Davis *et al.* also accounted for changes in crew size and vessel size, and those factors may account for the differences in the behaviour of their index.

Trends in our index of productivity differed substantially depending on the species mix targeted for each voyage, as indicated by the landings, and depending on the ocean basin implied by the announced destinations. For example, the productivity of vessels that targeted only sperm whales in the Atlantic (Figure 2, solid line) remained relatively high throughout the century, while the productivity of voyages that also or exclusively targeted baleen whales fell steadily from about 1830 onwards (Figure 2, dashed line). In the Pacific, the index for voyages targeting only sperm whales was highly variable over the century, whereas the index for voyages that also returned baleen whale products increased rather steadily from the mid-1830s when right whales, and later bowhead whales as well as humpback whales and gray whales, began to be taken in this ocean (Figure 3). In general, the index was higher for voyages with announced destinations in the Pacific than for voyages to the Atlantic.

Geography of Whaling

American 19th century whalers sought whales throughout most regions of the world's oceans (Figure 4). Although whaling occurred in the Arctic all the way to the edge of the summer sea ice, this was not so in the Antarctic. Whalers routinely rounded Cape Horn on their way to and from the Pacific, but they mostly did not venture farther south. American whalers made little use of the northern Indian Ocean, nor did they often visit waters around Indonesia and northern Australia. They apparently also shunned the central and western Caribbean Sea and the northeastern North Atlantic. In the remaining ocean areas, while the American whalers traversed most places (Figure 4, light blue dots) they encountered and caught whales primarily in specific areas, usually termed 'grounds' (for example, for sperm whales see Bannister *et al.* 2008). Catches on a given ground were primarily of a single species, with a few notable exceptions.

Prior to 1800, ship-based whalers were mostly confined to the Atlantic; the first voyages into the Indian and Pacific Oceans occurred in the 1790s. Subsequently, the areas where American whalers sought and caught whales changed again and again. In the period 1820 to 1840 they concentrated on sperm and right whales in the Atlantic and sperm whales in the Pacific along the equator and along the 30°N latitude (Figure 5). By mid-century the fishery had expanded north of 30°N in the Pacific to include right whales, and subsequently bowhead whales further north into the Bering Sea and Arctic Ocean (Figure 6). The fishery retreated into the Atlantic in its last decades, with the notable exception that bowhead whaling continued in the Western Arctic and in Hudson's Bay (Figure 7). Over the second half of the 19th century as the fishery was declining there was a smattering of sperm and right whaling in various parts of the Pacific. During this period other less valuable species of whales were also sought, primarily where they concentrated in coastal calving or breeding areas, including gray whales in the eastern North Pacific and humpback whales in the Pacific and Atlantic.

The changes in the distribution of whaling activity over the century seen in Figures 5 to 7 were accompanied by changes in the encounter rate of sperm whales, as defined above. In the Pacific the average encounter rate declined steadily (Figure 8, circles). In contrast, in the Atlantic the encounter rate remained relatively constant (Figure 8, crosses). The confidence intervals suggest a difference in the rates between the two oceans up to mid-century.

Comparing Voyage Productivity and Encounter Rates

The patterns of change in both the voyage productivity for sperm whaling voyages and the rates of encounters with sperm whales differed over the 19th century in the Atlantic and the Pacific. In the Atlantic both the voyage productivity and the encounter rates were relatively constant (compare Figures 2 and 8), neither showing any substantial trends. In contrast, in the Pacific the voyage productivity was relatively constant while the encounter rate declined markedly (compare Figures 3 and 8).

The Pacific results suggest that whalers selected where they searched in order to maintain high voyage productivity despite an overall decline in the rate at which whales were encountered, both on specific grounds (Bannister *et al.* 1981 and Hope and Whitehead 1991) and overall (Figure 8). Although such declines suggest decreasing abundance due to the removal of animals by whalers, this pattern could instead have occurred because the whales responded to whaling by becoming more difficult to sight or by moving undetected to new areas, as discussed above.

Our Atlantic results do not support the idea that declines in encounter rate were due to whales learning to avoid whalers. This is because encounter rates in the Atlantic did not decrease even though whaling continued there over more than a century. If sperm whales had learned to be more difficult to sight one would have expected the Atlantic encounter rates to have decreased regardless of any declines in abundance due to whaling. That the rates did not decrease at all suggests that any such learning was insufficient to cause substantial reduction in the rate at which they were encountered.

Also, the changing geography of whaling does not support the idea that declines in encounter rates were due to whales moving undetected to new areas. Whalers searched nearly all areas of the world's oceans for their prey (Figure 4), and would likely have been able to track changes in whale distribution because they continued to seek out and exploit new areas throughout the history of the fishery (Figures 5 to 7). Rapid changes in whaling grounds were seen, for example, between 1840 and 1850 when whalers shifted across the North Pacific in search of right whales (Josephson *et al.* 2008). The whales, for their part, favored certain ocean areas before whaling began, presumably for the availability of suitable concentrations of prey, areas that became known as whaling grounds. If whales were shifting to new areas in response to whaling, they would have been abandoning favoured habitat. There is no evidence that there were undetected shifts in sperm whale distribution in response to whaling, so this possibility remains speculative.

Thus we conclude that the declines in encounter rates are more likely to reflect decreases in numbers of whales than changes in whale behaviour, suggesting that 19th century whaling in the Pacific reduced the abundance of sperm whales substantially more than Whitehead's global estimate of 29%. Further, the ability of whalers to maintain high voyage productivity in the face of declining abundance suggests that indexes of voyage productivity, such as ours and that of Davis *et al.*, are of little use for assessing or measuring the effects of whaling on the target populations of whales.

If whaling did decrease sperm whale abundance in the Pacific, why did this not happen in the Atlantic? One possibility of course is that whaling was insufficiently intense there to reduce abundance greatly. It is worth noting that in the Atlantic voyage productivity was always lower than in the Pacific (compare Figures 2 and 3), despite the greater costs of operating over long distances, and that Atlantic rates of encounter (Figure 8) were lower, at least in the first part of the century. These differences likely explain the initial shift of sperm whaling into the Pacific, and suggest that sperm whaling in the Atlantic was less profitable and hence less intense than in the Pacific.

However, the situation in the Atlantic is more complicated than that in the Pacific precisely because the greater productivity of Pacific voyages attracted a larger proportion of the whaling fleet, at least in the first part of the century. In the second part of the century, as the rates of encounters with sperm whales declined in the Pacific, a decreasing proportion of voyages went there (Figures 5 to 7). We have attempted to account for this shift in emphasis by computing ocean-specific encounter rates only for voyages that actually whaled in each ocean, omitting from our rate calculations data from voyages that merely transited the Atlantic, for example. However, we have not accounted for some other factors possibly affecting whaling intensity and success. For example, there was a higher proportion of vessels that were rigged as ships and a higher proportion of larger vessels that whaled in the Pacific. Thus, because of the expansion into the Pacific and subsequent retreat back into the Atlantic, a closer examination of the temporal and regional patterns of sperm whaling in the Atlantic is needed to understand the apparent lack of decrease in sperm whale numbers there.

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Figure 1. Our index of whaling voyage productivity for all voyages according to their year of departure (solid line) and the index of voyage productivity for voyages departing from New Bedford by Davis *et al.* (1997) (rescaled by dividing by 4, dashed line).

Figure 2. Our index of whaling vessel productivity for voyages with announced destinations in the Atlantic for those that returned only sperm oil (solid line) and those that also or only returned baleen oil and baleen (dashed line).

Figure 3. Our index of whaling vessel productivity for voyages with announced destinations in the Pacific for those that returned only sperm oil (solid line) and those that also or only returned baleen oil and baleen (dashed line).

Figure 4. Locations of American whaling vessels on days with whale encounters (sightings and catches) by species (red=right whales, dark blue=sperm whales, purple=humpback whales, green=bowhead whales, brown=gray whales) and on days without encounters (light blue) for all years from 1790 to 1924.

Figure 5. Locations of American whaling vessels on days with whale encounters (sightings and catches) by species (red=right whales, dark blue=sperm whales, purple=humpback whales, green=bowhead whales, brown=gray whales) and on days without encounters (light blue) for all years from 1821 to 1840.

Figure 6. Locations of American whaling vessels on days with whale encounters (sightings and catches) by species (red=right whales, dark blue=sperm whales, purple=humpback whales, green=bowhead whales, brown=gray whales) and on days without encounters (light blue) for all years from 1841 to 1875.

Figure 7. Locations of American whaling vessels on days with whale encounters (sightings and catches) by species (red=right whales, dark blue=sperm whales, purple=humpback whales, green=bowhead whales, brown=gray whales) and on days without encounters (light blue) for all years from 1876 to 1924.

Figure 8. Encounter rates of sperm whales by American offshore whaling vessels per day at sea when whaling in the Pacific (circles) and when whaling in the Atlantic (crosses) Oceans, with 95% confidence intervals.