1986

Cetacean High-Use Habitats of the Northeast United States Continental Shelf

Robert D. Kenney
University of Rhode Island, rkenney@uri.edu

Howard E. Winn
University of Rhode Island

Citation/Publisher Attribution

Kenney, R. D., & Winn, H. E. (1986). Cetacean High-Use Habitats of the Northeast United States Continental Shelf. *Fishery Bulletin, 84*(2), 345-357. Retrieved from https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/1986/842/kenney.pdf.
Available at: https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/1986/842/kenney.pdf

CETACEAN HIGH-USE HABITATS OF THE NORTHEAST UNITED STATES CONTINENTAL SHELF[1]

ROBERT D. KENNEY AND HOWARD E. WINN[2]

ABSTRACT

Results of the Cetacean and Turtle Assessment Program previously demonstrated at a qualitative level that specific areas of the continental shelf waters off the northeastern U.S. coast consistently showed high-density utilization by several cetacean species. We have quantified, on a multispecies basis and with adjustment for level of survey effort, the intensity of habitat use by whales and dolphins, and defined areas of expecially high-intensity utilization. The results demonstrate that the area off the northeast United States, which is used most intensively as cetacean habitat, is the western margin of the Gulf of Maine, from the Great South Channel to Stellwagen Bank and Jeffreys Ledge. Secondary high-use areas include the continental shelf edge and the region around the eastern end of Georges Bank. High-use areas for piscivorous cetaceans are concentrated mainly in the western Gulf of Maine and secondarily at mid-shelf east of the Chesapeake region, for planktivores in the western Gulf of Maine and the southwestern and eastern portions of Georges Bank, and for teuthivores along the edge of the shelf. In general, habitat use by cetaceans is highest in spring and summer, and lowest in fall and winter.

From October 1978 through January 1982, the Cetacean and Turtle Assessment Program (CETAP) at the University of Rhode Island conducted surveys of the waters of the U.S. continental shelf from Cape Hatteras, NC, to the northern Gulf of Maine. The purpose of these surveys was to provide data on the distribution and abundance of whales, dolphins, and sea turtles inhabiting the northeast shelf for input to decision-making relative to offshore oil and gas resource development. Twenty-six species of cetaceans were observed during the study, and their distributions have been described in some detail (CETAP 1982). Each species exhibited a distinctive pattern of distribution in space and time, inhabiting some small portion(s) of the study area at higher relative densities.

When comparing distributions of individual species, there appear to be specific geographic areas which consistently contained higher abundances of several cetacean species. This phenomenon had been noted during the CETAP study (CETAP 1982), but had not been analyzed quantitatively. An individual species approach to the analysis of such multispecies phenomena has certain limitations. One cannot simply combine the sighting distributions of several species; the different cetacean species vary widely in size and may have quite different ecological requirements. An additional complication in a study of habitat use, based on sighting data, is introduced by the uneven allocation of sighting effort. One cannot be certain whether a lack of sightings is due to absence of whales or absence of observers, or, conversely, whether a concentration of sightings represents a real concentration of whales or simply a concentration of effort. Thus it is difficult to simply or directly combine single-species sighting distributions in any sort of multispecies habitat use analysis. In this paper, we have attempted to synthesize, from the CETAP individual species sighting data, a measure of the intensity of habitat use by the total cetacean fauna in the study area which accounts for both interspecific differences and differences in allocation of effort. These results then serve to delineate those specific habitat areas which are used at particularly high levels by whales and dolphins off the northeastern United States.

An underlying assumption in this paper is that a habitat which is occupied by whales or dolphins is necessarily utilized by them. Previous results from CETAP data have shown that the distribution of sightings of a particular species where definite feeding behavior was observed tended to closely mirror the overall sighting distribution for that species. Only feeding activity at or very near the surface can be seen by observers on ships or airplanes, but much feeding behavior likely occurs below the surface. For some species, observations of surface feeding are very rare. In addition, cetaceans are large mammals

[1]This report has been reviewed by the Minerals Management Service and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

[2]Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882-1197.

Manuscript accepted July 1985.
FISHERY BULLETIN: VOL. 84, NO. 2, 1986.

with high metabolic rates and accordingly high feeding rates. They are estimated to consume prey equivalent to 1.5-4% of their body weight daily (Sergeant 1969; Lockyer 1981), with some estimates for smaller species as much as 10% of body weight per day (e.g., Smith and Gaskin 1974). The CETAP study concluded that cetaceans "would be expected to feed virtually every day while in the study area" and that "each species of cetacean was likely feeding, either at the surface or below, in any area in which it was seen regularly" (CETAP 1982, p. 417). For the purposes of the current study, we have also followed this reasoning and assumed that a habitat which is being occupied by one or more cetacean species is therefore being utilized by those species as a feeding area.

METHODS

The CETAP study area was defined as the waters of the U.S. continental shelf north of Cape Hatteras, from the shoreline to 5 nmi (9.3 km) seaward of the 1,000 fathom (1,829 m) isobath. Surveys were conducted from October 1978 through January 1982. Data collected from two types of surveys have been used in this analysis:

1) *Dedicated aerial surveys*: Random transect aerial surveys were conducted in defined blocks within the study area, including both regular surveys throughout the year and special surveys targeted at endangered species, particularly right whales. The primary objective of these surveys was to estimate the absolute abundance, e.g., the total number of individuals in the population, of each species in the study area, using line transect census methods (Burnham et al. 1980; Scott and Gilbert 1982). This methodology requires consistent use of rigorously standardized sampling, e.g., use of the same platform, even allocation of sampling across the different blocks, and random selection of transects within a block.

The two aircraft used for these surveys were a Beechcraft[3] AT-11 and a Cessna 337-G Skymaster, both twin-engine planes. The AT-11 crew consisted of a pilot, a navigator, and four observers; two observers at a time were stationed in a clear acrylic observation bubble in the nose of the plane. The Skymaster carried a pilot, a navigator, and two observers, who sat in the rear seats and watched out the side windows. All surveys were conducted at an altitude of 750 ft (229 m) and a groundspeed of 120 kn (222 km/h).

For any particular survey, a series of parallel track lines was flown. For the regular surveys, the lines sampled were randomly chosen from a pool of lines running northwest-southeast (roughly perpendicular to the bathymetry) and spaced at 2 nmi intervals throughout the block to be sampled. For the endangered species surveys, the lines were systematically spaced at a predetermined interval, with the first line placed at a randomly determined distance from the edge of the block.

2) *Platforms of opportunity (POP) surveys*: Trained observers were placed aboard various ships and aircraft operating within the study area in order to collect distributional data to supplement the dedicated surveys. The platforms most often used included Coast Guard cutters, U.S. and foreign oceanographic and fisheries research vessels, and Coast Guard fisheries patrol and thermography aircraft. The track of the ship or aircraft was wholly determined by its primary mission. These data could not be used in abundance estimation because effort was not allocated randomly or evenly, and the platforms used were not exactly comparable.

Observers on both types of surveys recorded a variety of information. The data collected included date, time, latitude and longitude, platform heading, beginning and end of periods when the observer(s) were actively on watch, and environmental information (air temperature, water temperature, depth, weather, visibility, sea state, wind direction, and cloud cover). The data were recorded at each sighting, as well as at periodic intervals (typically 5 min for aerial and 30 min for shipboard surveys) during all on-watch periods. This allowed for subsequent reconstruction of flight-cruise tracks. Additional data recorded at sightings included species, reliability of identification, number of animals, distance from the platform, animal heading, and behaviors.

The data were transcribed from the field forms to coding forms, keypunched, and input to a computer data base. A number of quality control steps were included in the process, and all discovered errors were corrected. In addition to the two types of survey data described above, historical sighting data collected prior to CETAP and opportunistic sighting data provided by fisherman, mariners, whale-watchers, fish-spotters, pilots, etc. are included in the CETAP data. None of these data have associated track-line information, and are therefore not included in this paper. After completion of the CETAP

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

study, the entire data base was archived on magnetic tape at the University of Rhode Island Academic Computer Center. The data base is very large, comprising nearly 70,000 entries and 112 variables; it includes almost 25,000 sightings of cetaceans, sea turtles, or other large marine animals (e.g., sharks, ocean sunfish, swordfish, rays, etc.).

For this paper, the study area was partitioned into blocks measuring 10 minutes of latitude by 10 minutes of longitude. The area of the blocks ranges from about 243 km^2 at the northern extreme of the study area to about 281 km^2 at the southern end, due to the curvature of the earth's surface and resulting convergence of the meridians toward the north pole. The data were further grouped by calendar seasons across all the years of sampling. All dedicated aerial and POP data which met defined criteria were included in the analysis. These criteria included observer(s) formally on watch, clear visibility of at least 2 miles, and sea states of Beaufort 3 or lower. Although the dedicated aerial and POP data were not directly compatible for the purpose of absolute abundance estimation, we are justified in combining them for this analysis. An examination of sighting effort in the 1979 CETAP data (Hain et al. 1981) demonstrated a significant correlation between numbers of sightings and length of line surveyed for both aerial and POP surveys. Reanalysis of these same data shows that the average number of sightings per mile of track line surveyed was somewhat higher for the POP surveys, but that the difference is not statistically significant at the 5% level (paired Student's *t*-test). Since we are in effect using the number of sightings per unit length of track line as a measure of relative abundance in this analysis, the two data types can be combined.

To remove any bias due to uneven allocation of sighting effort among the blocks, the effort was first quantified. A computer program was developed which calculated the length of track line surveyed each season within each of the 10-minute blocks, including only line segments surveyed within the criteria defined above. Each line surveyed is recorded in the data base as a sequence of latitude-longitude positions. For any pair of successive positions, the length of track line between the points (D, in km) can be calculated by:

$$D = 111.12 \arccos [\sin (X_1) \sin (X_2) + \cos (X_1) \cos (X_2) \cos (Y_2 - Y_1)],$$

where X_1 and X_2 are the latitudes of the two positions, and Y_1 and Y_2 are the corresponding longitudes. This calculates great circle distance. Flight or cruise tracks would actually be rhumb lines rather than great circles, but the algorithm required to calculate rhumb line distance is much more complex. Furthermore, for two points around 10 km apart, typical of track line segments in the data, great circle and rhumb line distance differ by <1 m, an error of <0.01%.

For a pair of points within a single 10-minute block, the length of the intervening line segment is simply assigned to that block. The difficulty arises for successive points located in separate blocks. It is then necessary to find the point(s) of intersection where the track line crosses any block boundary(ies). The bulk of the computer program is concerned with this procedure. For a pair of points in separate blocks, the equation describing the great circle through the points is defined. The point where that line crosses a boundary is then determined by inserting the latitude or longitude value defining the boundary into the great circle equation, and then solving for the other coordinate. The line segment which originally spanned two or more blocks is thereby partitioned into smaller segments, each wholly contained in a single block, whose lengths are then calculated as above. The final step in the procedure is to sum the lengths of all the line segments within the block, which represents the amount of sighting effort expended in the block.

All cetacean sightings made during track segments meeting the defined criteria were also extracted from the data base. These data were summarized to produce, for each species, the total number of individual animals sighted in each block and season. (This is not to say that this number represents all different individuals. An individual may be sighted repeatedly by different surveys, but this is taken into account by the correction for effort.) In order to combine different species, the number of animals of a particular species was multiplied by the species' estimated average body weight to calculate biomass sighted per block and season. The biomass data for each species were then partitioned into three feeding classes—piscivorous, teuthivorous, and planktivorous—based upon the estimated percentages of each species' diet composed of fish, squid, and zooplankton, respectively. In an earlier analysis of prey consumption by cetaceans in the CETAP study area, Scott et al.[4] classified each species into a single category based on its principal prey type;

[4]Scott, G. P., R. D. Kenney, T. J. Thompson, and H. E. Winn. 1983. Functional roles and ecological impacts of the cetacean community in the waters of the northeastern U.S. continental shelf. Paper presented at 1983 annual meeting, International Council for the Exploration of the Sea, ICES C.M. 1983/N:12.

however, we felt that using the estimated proportion of the diet comprised of the different prey types was a more realistic representation of what was actually occurring in the ecosystem. The body weight and prey preference estimates were taken from Kenney et al. (1985), who had based their estimates on an extensive literature review. For three species not included in that reference—beluga, false killer whale, and rough-toothed dolphin—body weight and prey preference estimates were based on Watson (1981) and Nishiwaki (1972). For the categories of sightings which were not completely identified, the body weight and prey percentages were calculated as averages for all species included in the category and weighted by the number of sightings of each. (It might be argued that the unidentified categories should be excluded totally and that their inclusion introduces too much uncertainty. However, we felt that excluding them would eliminate many potentially valuable observations and that including them would provide a closer measure of habitat use. Some of the categories can be narrowed to only a couple of species, and the number of sightings overall is a valid basis for estimating the probability of an unidentified sighting being a particular species.)

The biomass data were then summed for all species in each block and season, as well as for the piscivorous, teuthivorous, and planktivorous subsets. Values for endangered species biomass were also calculated by summing the data for right, humpback, blue, fin, sei, and sperm whales, as well as for the estimated proportion of the unidentified categories made up of these species. The biomass data for each block and season were then divided by the corresponding effort data, resulting in values of biomass per unit effort (BPUE) in units of kilograms of cetacean sighted per kilometer of track line surveyed (kg/km). The final data set therefore had, for each block, BPUE values for all cetaceans, for endangered species only, and for the piscivorous, teuthivorous, and planktivorous components of the cetacean fauna for each season and for the entire year.

The simplest technique for looking at the pattern of high-intensity habitat use by cetaceans is to plot the blocks with the highest values of BPUE. Obviously, the blocks with the highest BPUE values within any of the individual data sets are those with the highest intensity of habitat use. The question becomes one of defining the cutoff point in each distribution for selecting the highest values. The frequency distributions of each of the BPUE data sets were examined for any patterns which might be useful as an objective criterion to define a lower bound for the high-use blocks (e.g., bimodal distributions, or 2 standard deviations above the mean of a normal distribution). Log-survivorship plots (plotting BPUE vs. log of the number of blocks with higher BPUE values; see Fagen and Young 1978) were also tried to look for changes in slope which could serve as a means of numerically defining this boundary. When these techniques failed to select any specific value for the cutoff point, we opted to use simple percentile rankings to classify the blocks for plotting the results.

The final step in the analysis was to develop an index which would serve to define those areas which are most important as cetacean habitat. By "important" we include both the level of habitat use and the management priority of the individual species. Habitat requirements for an individual probably depend heavily upon prey type, so each of the data sets for the three feeding classes were included in this process. Since management objectives concentrate on the endangered species, the endangered species data sets were also included. Since the endangered species data are also part of the feeding type data, the former are in effect being included twice. This gives the endangered species extra weight in the index, in accord with both their endangered status and management focus. For each seasonal set of BPUE data for the endangered species and the three feeding classes, blocks were assigned points as follows: 5 if the BPUE was greater than the 99th percentile value for that data set, 3 if it was between the 95th and 99th percentiles, 1 if between the 90th and 95th percentiles, and 0 otherwise. The value of the index for a block is then the sum of these point values for all data sets. Since there were four seasons and four BPUE variables used, the maximum possible value for the index in any block would be 80 ($4 \times 4 \times 5$). For lack of a more concise term, we shall refer to this as Habitat Use Index, although it does have the additional dimension of focus on endangered species. Since this index is based on only the top 10% of each of the 16 individual data sets, it provides a simple way to point out those blocks which repeatedly stand out as high-use habitat in more than one season and/or for more than one prey type.

RESULTS

During the CETAP study, observers on dedicated aerial or POP surveys operating within the defined survey criteria made 5,304 sightings of 26 different species of whales and dolphins. These include sighting of individuals in three genera—*Globicephala*, *Mesoplodon*, and *Kogia*—which could only be identified in the field to genus. In addition, there were 2,039 sightings of 30 more or less unidentified categories of cetaceans, bringing the grand total to 7,343 sightings. Table 1 lists all the observed cetacean species and unidentified categories, with numbers of sightings of each. It also shows, for each species, the values used in this analysis for estimated average body weight and percentage of diet comprised of the three major prey types.

Overall, 1,476 10-minute blocks were sampled by CETAP dedicated and POP surveys, with a total of over 373,000 km of track line surveyed within acceptable criteria. Somewhat fewer blocks were sampled during any one season. Sighting effort was most in-

TABLE 1.—List of cetacean species and unidentified categories sighted by CETAP dedicated aerial and POP surveys on the northeast U.S. shelf, showing number of sightings, estimated body weight, and estimated percentage of the diet comprised of fish, squid, and zooplankton. Endangered species are identified by *.

Species or category	No. of sightings	Body weight (kg)	Percent of diet		
			Fish	Squid	Zooplankton
Right whale, *Balaena glacialis**	173	40,000	0	0	100
Humpback whale, *Megaptera novaeangliae**	409	25,000	95	0	5
Sperm whale, *Physeter catodon**	258	20,000	20	80	0
Blue whale, *Balaenoptera musculus**	2	70,000	0	0	100
Fin whale, *B. physalus**	946	30,000	90	0	10
Sei whale, *B. borealis**	62	13,000	0	0	100
Minke whale, *B. acutorostrata*	215	4,500	95	0	5
Beaked whale, *Mesoplodon* sp.	11	1,200	0	100	0
Goosebeaked whale, *Ziphius cavirostris*	4	1,900	0	100	0
Northern bottlenose whale, *Hyperoodon ampullatus*	4	4,700	5	95	0
Beluga whale, *Delphinapterus leucas*	1	420	100	0	0
Pygmy/dwarf sperm whale, *Kogia* sp.	1	300	0	100	0
Pilot whale, *Globicephala* sp.	537	850	0	100	0
Killer whale, *Orcinus orca*	4	3,000	90	10	0
False killer whale, *Pseudorca crassidens*	1	500	50	50	0
Pygmy killer whale, *Feresa attenuata*	1	150	100	0	0
Gray grampus, *Grampus griseus*	421	340	0	100	0
Bottlenose dolphin, *Tursiops truncatus*	828	150	100	0	0
White-beaked dolphin *Lagenorhynchus albirostris*	10	150	50	50	0
Atlantic white-sided dolphin, *L. acutus*	374	120	90	10	0
Rough-toothed dolphin, *Steno bredanensis*	1	100	50	50	0
Saddleback dolphin, *Delphinus delphis*	340	65	85	15	0
Striped dolphin, *Stenella coeruleoalba*	63	55	40	60	0
Spotted dolphin, *S. attenuata* or *plagiodon*	51	50	20	80	0
Spinner dolphin, *S. longirostris*	3	50	20	80	0
Harbor porpoise, *Phocoena phocoena*	584	45	95	5	0
Unidentified (unid.) whale	263	25,000	71	12	17
Unid. large whale	139	27,900	70	11	19
Unid. large whale, not *B. glacialis*	2	26,700	77	12	11
Unid. large whale, not *P. catodon*	5	29,200	78	0	22
Unid. rorqual	30	24,800	88	0	12
Unid. rorqual, not *B. acutorostrata*	62	27,900	87	0	13
Unid. rorqual, not *M. novaeangliae*	6	24,800	86	0	14
P. catodon or *M. novaeangliae*	2	23,100	66	31	3
P. catodon, *M. novaeangliae*, or *B. glacialis*	6	26,600	52	25	23
B. musculus, *physalus*, or *borealis*	127	29,000	84	0	16
Unid. medium whale	68	4,080	81	15	4
Unid. beaked whale	19	2,090	1	99	0
Unid. beaked whale or *P. catodon*	2	17,600	18	72	0
Mesoplodon sp. or *Z. cavirostris*	2	1,390	0	100	0
Unid. blackfish	4	863	1	99	0
Unid. large blackfish	1	864	1	99	0
Globicephala sp. or *P. crassidens*	6	849	0	100	0
Unid. dolphin	785	133	74	26	0
Unid. beaked dolphin	120	117	85	15	0
Unid. dolphin, not *G. griseus*	161	96.7	90	10	0
Unid. long-beaked dolphin	11	112	84	16	0
Lagenorhynchus sp.	10	121	89	11	0
Lagenorhynchus sp. or *T. truncatus*	2	141	96	4	0
L. acutus or *D. delphis*	23	93.8	88	12	0
Stenella sp.	86	52.7	31	69	0
Stenella sp., not *S. longirostris*	64	52.8	31	69	0
Stenella sp. or *T. truncatus*	8	126	83	17	0
S. coeruleoalba or *T. truncatus*	1	136	91	9	0
S. attenuata/plagiodon or *T. truncatus*	3	138	90	10	0
Stenella sp. or *D. delphis*	21	59.6	61	39	0

tense during spring, followed in descending order by summer, fall, and winter. Table 2 summarizes the sighting effort by season and for the entire year.

The BPUE data are summarized in Table 3. The distributions of BPUE values for all categories and seasons were very similar. Each distribution was highly skewed toward lower values. This can be seen from the table; mean values ranged between 33 and 423 kg/km, but maximum values were as high as 33,747 kg/km. In 20 of the 25 cases, the median value was 0, and in 9 of these the 75th percentile value was also 0, indicating that no cetaceans of that particular category were seen in one-half or three-quarters, respectively, of the blocks surveyed. In fact, in two cases (endangered species and planktivores sighted in winter) even the 90th percentile value was 0; no endangered or plankton-feeding cetaceans were observed in 9 out of 10 blocks surveyed in the winter.

The overall pattern of high habitat use by cetaceans is depicted in Figure 1, which shows those 10-minute blocks with the top 10% of the whole-year BPUE values (all species combined). The figure also identifies locations to be used for geographic reference. Three principle high-use areas can be delineated: 1) the western margin of the Gulf of Maine, from the Great South Channel northward to Jeffreys Ledge, 2) the eastern portions of Georges Bank, along with the Northeast Channel and relatively deep basin north of the bank, and 3) the continental shelf edge. There are also scattered high-use blocks in other areas.

TABLE 2.—Summary of sighting effort in 10-minute blocks, expressed as kilometers of track line surveyed within acceptable criteria, for CETAP dedicated and POP surveys.

	Season				
	Winter	Spring	Summer	Fall	Total
Blocks sampled	1,179	1,344	1,395	1,169	1,476
Mean effort per block	40.3	108.0	80.7	58.2	252.9
Standard deviation	32.9	104.9	56.1	47.6	207.9
Maximum effort per block	372	1,137	596	546	2,389
Total effort	47,506	145,204	112,576	67,994	373,280

TABLE 3.—Mean, median, and maximum values of biomass sighted per unit of sighting effort, by season and for the entire year, for all cetacean species combined, endangered species only, and fish-, squid-, and plankton-feeding cetaceans.

		Biomass per unit effort (kg/km)		
Cetacean category	Season	Mean	Median	Maximum
All cetaceans	All	368	67	15,170
All cetaceans	Winter	234	[1]0	23,049
All cetaceans	Spring	423	2	20,928
All cetaceans	Summer	386	0	28,447
All cetaceans	Fall	270	0	33,747
Endangered species	All	296	0	15,170
Endangered species	Winter	198	[1,2]0	22,048
Endangered species	Spring	350	0	20,268
Endangered species	Summer	323	[1]0	27,478
Endangered species	Fall	190	[1]0	33,072
Piscivores	All	205	21	6,920
Piscivores	Winter	139	[1]0	16,266
Piscivores	Spring	256	1	15,446
Piscivores	Summer	235	0	22,483
Piscivores	Fall	158	0	23,995
Teuthivores	All	83	1	4,249
Teuthivores	Winter	62	[1]0	11,879
Teuthivores	Spring	80	0	3,582
Teuthivores	Summer	83	0	5,380
Teuthivores	Fall	79	0	5,625
Planktivores	All	80	0	12,323
Planktivores	Winter	33	[1,2]0	8,190
Planktivores	Spring	87	0	5,874
Planktivores	Summer	68	[1]0	12,910
Planktivores	Fall	33	[1]0	5,805

[1]75th percentile value was also 0.
[2]90th percentile value was also 0.

Figure 2 shows the patterns of high habitat use, again as the upper 10% of BPUE values, for the entire cetacean community in each of the four seasons. The seasonal patterns do not show any major differences; however, a slight north-south shift in the pattern is evident. The number of high-use blocks is higher in the northern portion of the area and lower in the southern portion during spring and summer than during fall and winter. It should be emphasized that the plots in Figure 2 do not indicate differences in magnitude of utilization intensity between seasons, but only pattern differences. Since the blocks which are plotted are the upper 10% of the BPUE values for each seasonal distribution, the numbers of blocks plotted for each season are fairly equivalent. For example, it appears from the plots that the shelf edge may be more intensely used in the winter than during the other seasons, but actually the reverse is true. It is simply that the blocks with highest winter utilization tend to be on the shelf edge, but the intensity of use in these blocks is still lower. Seasonal differences in intensity of habitat use can be seen by referring back to Table 3. The intensity of habitat use is highest in the spring and second highest in the summer for all categories except the teuthivores, where the summer utilization is most intense and spring and fall very close behind. There

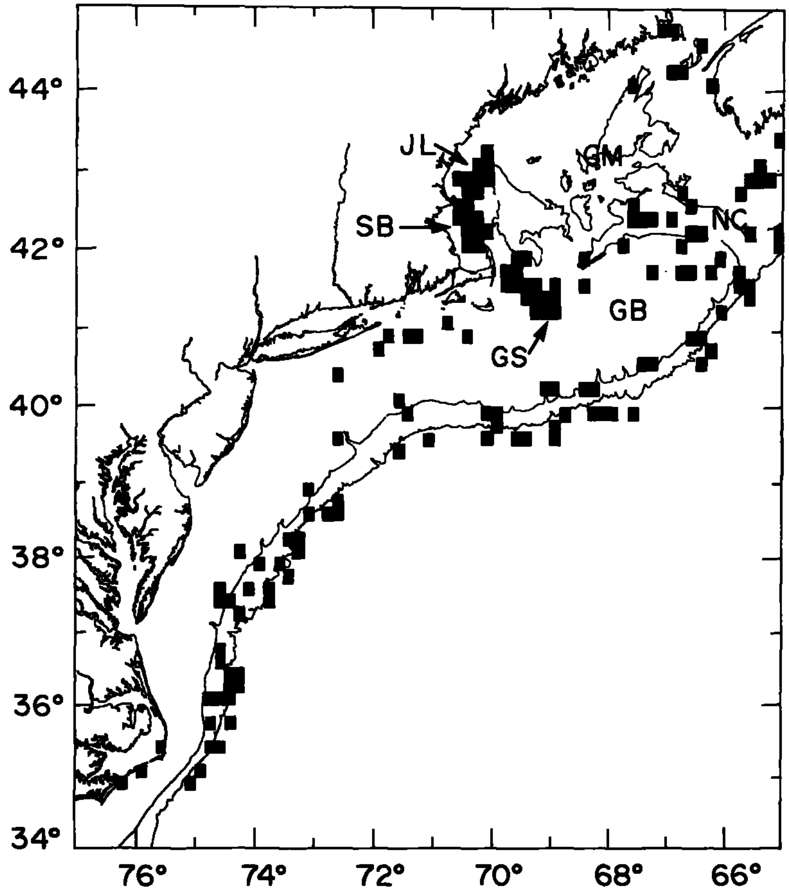

FIGURE 1.—Plot of 10-minute blocks with total cetacean biomass per unit effort values in the top 10% of all blocks. GM = Gulf of Maine; GB = Georges Bank; NC = Northeast Channel; JL = Jeffreys Ledge; SB = Stellwagen Bank; GS = Great South Channel.

is a general pattern of reduced utilization during the fall and winter.

Figure 3 shows the whole-year patterns of high habitat usage for the four subsets of the total cetacean community. The pattern for endangered species shows only slight differences from the total community pattern seen in Figure 1. Differences from the total community pattern become somewhat greater in the piscivorous component. The intensity of utilization along the shelf edge is less, but there appears an area or areas of high use at midshelf east of the Chesapeake Bay region. The planktivorous component shows a distinctive pattern. There are only scattered high-use blocks in the southern half of the area. In the northern half of the area, the pattern is similar to those for the entire community, endangered species, or piscivores, except that there are more high-use blocks in the central portion of the Gulf of Maine and on the southern part of Georges Bank. The teuthivorous component shows the most distinct pattern, with a dense concentration of high-use blocks along the shelf edge in the southern half of the area and a less dense concentration along the more northern shelf edge and in the vicinity of the Northeast Channel.

Finally, Figure 4 presents the overall composite pattern of high-use areas, plotting those 10-minute blocks with Habitat Use Index values in the upper 5%, 10%, and 20% of all blocks sampled. Of the total of 1,476 blocks surveyed, 889 had index values of 0 and 587 were 1 or greater. The maximum index value was 49 for a block located at the northern end of Stellwagen Bank. Table 4 lists the blocks in the upper 1% of the distribution, showing their locations. Of those 16 blocks, 13 are in the western Gulf of Maine between the Great South Channel and Jeffreys Ledge. This area shows the densest concentration of high-use blocks in Figure 4. The secondary

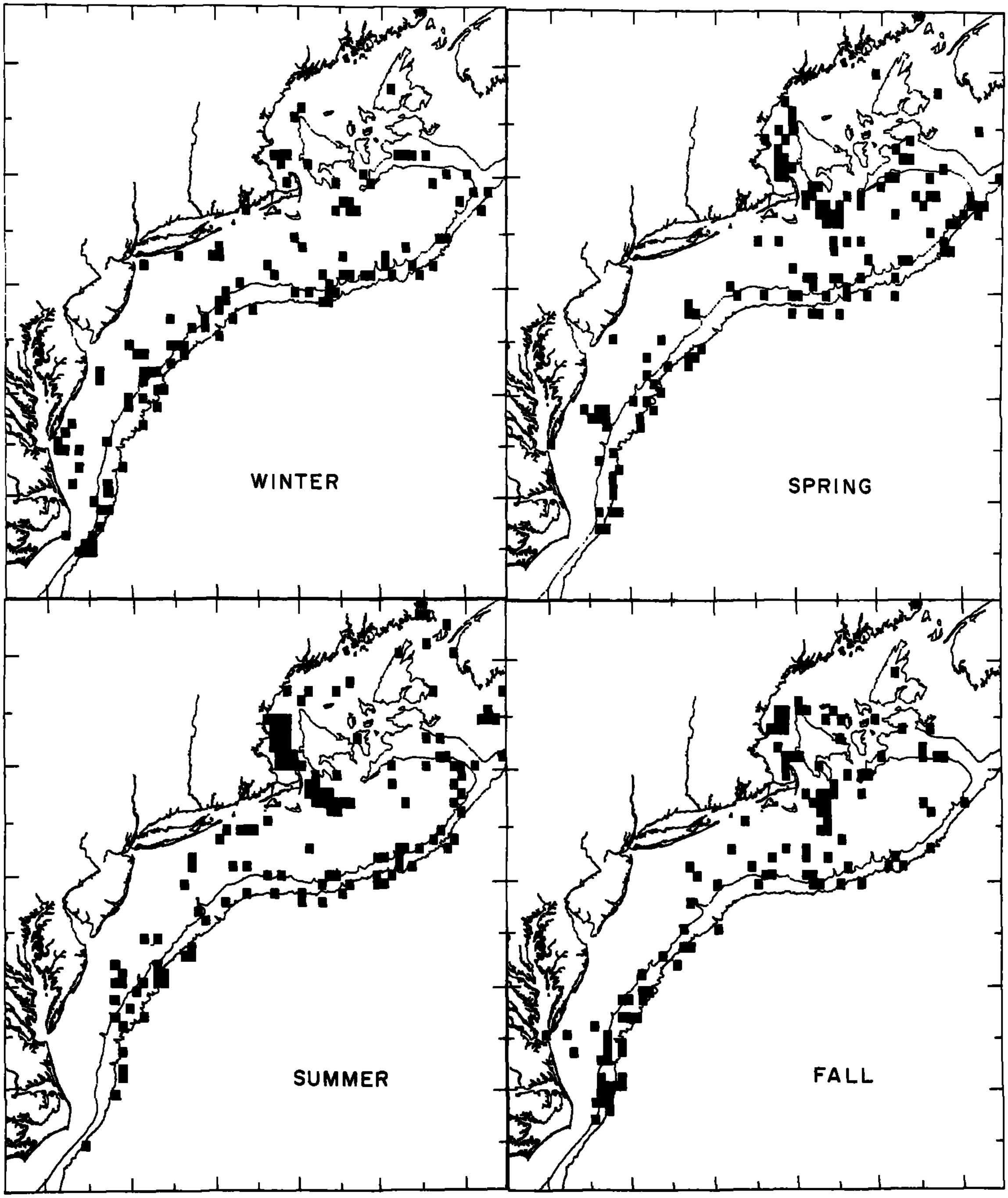

FIGURE 2.—Seasonal patterns of the top 10% of total cetacean biomass per unit effort values.

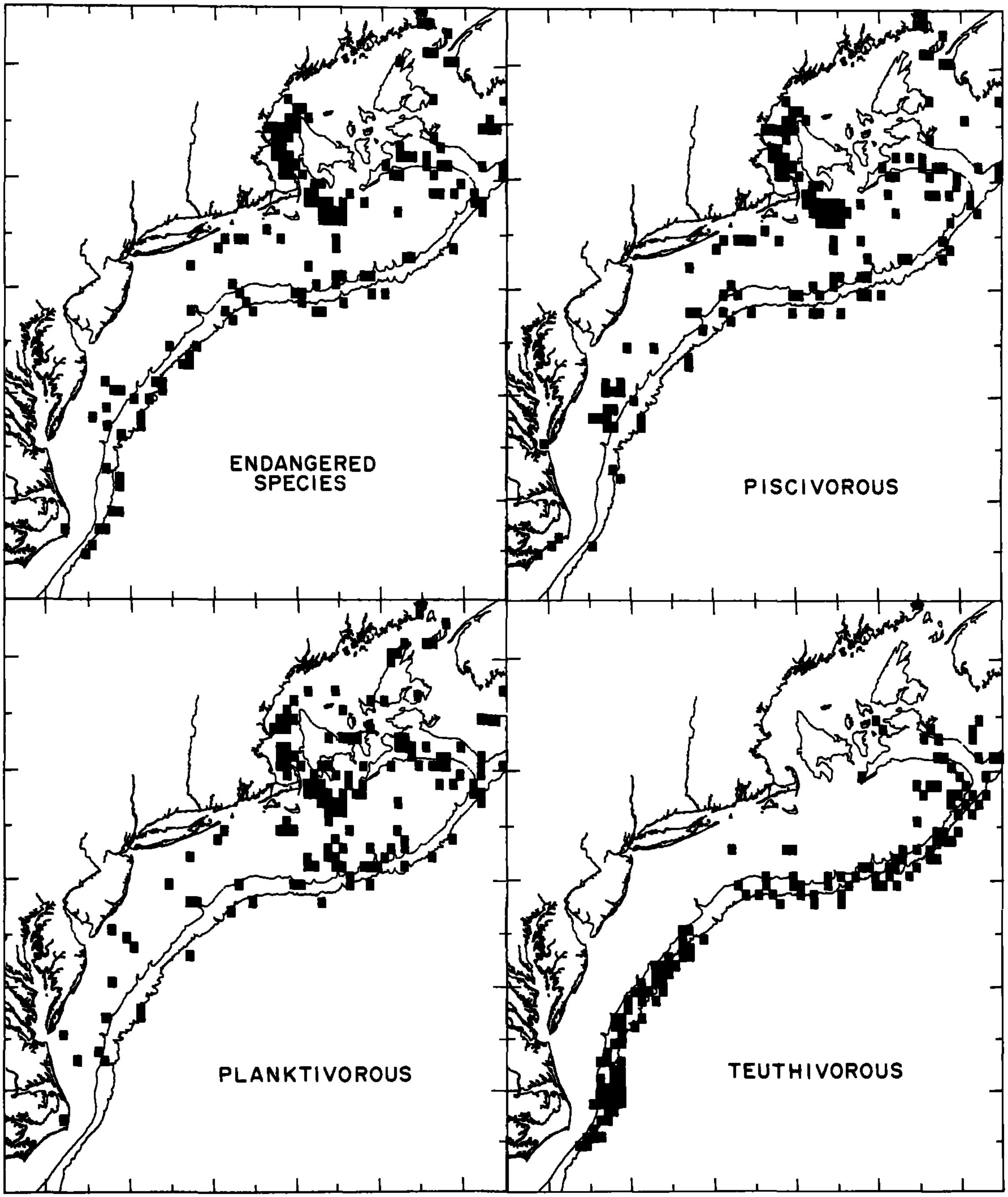

FIGURE 3.—Blocks with top 10% of cetacean biomass per unit effort values for four subsets of the total cetaceans: endangered species (right, humpback, sperm, blue, fin, and sei whales), fish-eating component, plankton-eating component, and squid-eating component.

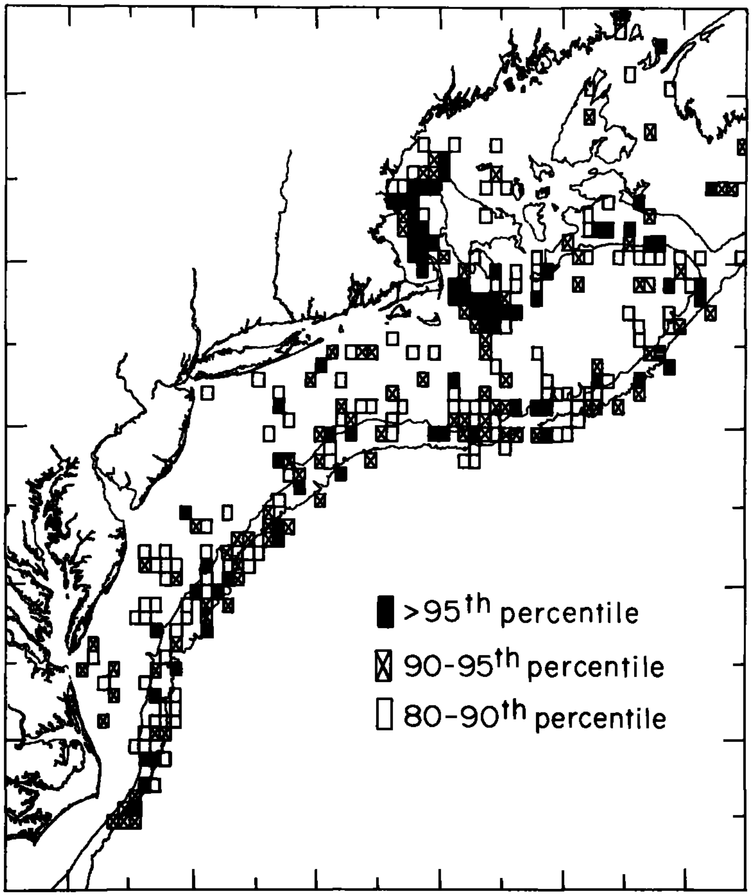

FIGURE 4.—Plot of Habitat Use Index in 10-minute blocks, showing blocks with values in the upper 5%, 10%, and 20% of the distribution.

TABLE 4.—List of the 10-minute blocks with Habitat Use Index values in the upper 1% of all blocks sampled, in descending order, with the latitude and longitude of the block center and the location of the block.

Utilization index	Central point of block		General location
49	42°25′	70°25′	Northern end—Stellwagen Bank
41	41°25′	69°15′	Great South Channel
36	41°25′	69°25′	Great South Channel
34	42°15′	66°25′	Northeast Channel
33	41°35′	69°25′	Great South Channel
32	42°15′	70°25′	Stellwagen Bank
32	42°15′	70°05′	Stellwagen Bank
32	40°35′	67°25′	Georges Banks—Powell Canyon head
29	42°15′	70°15′	Stellwagen Bank
29	42°05′	70°15′	Stellwagen Bank
28	41°25′	69°05′	Great South Channel
27	41°45′	69°45′	Great South Channel
27	41°25′	68°55′	Great South Channel
26	43°15′	69°55′	Northern end—Jeffreys Ledge
26	42°55′	65°35′	Off Browns Bank
26	41°15′	69°15′	Great South Channel

concentrations of high-use blocks tend to be around the perimeter of Georges Bank and along the continental shelf edge.

DISCUSSION

The CETAP sighting data for some individual species showed a concentration of sightings along the western margin of the Gulf of Maine. This analysis has demonstrated quantitatively that this area is the most intensely used cetacean habitat on the northeast U.S. continental shelf. It comprises a major feeding ground for fin whales, humpback whales, right whales, minke whales, and white-sided dolphins. Humpbacks and fin whales are known to feed heavily upon the American sand lance, *Ammodytes americanus*, a small schooling fish (CETAP 1982; Hain et al. 1982; Mayo 1982; Mitchell 1973, 1975c; Overholtz and Nicolas 1979), and the minke whales and white-sided dolphins likely do so as well (CETAP 1982; Mayo 1982; Mitchell 1975b). The sand lance populations of the western North Atlantic have increased dramatically since the mid-1970's (Sherman et al. 1981). Meyer et al. (1979) described the western Gulf of Maine, especially Stellwagen Bank and east of Cape Cod, as an area of extremely dense sand lance populations. Data from the National Marine Fisheries Service 1979-1981 groundfish surveys (T. R. Azarovitz[5]) also shows peak *Ammodytes* abundance in the Stellwagen Bank-Jeffreys Ledge area. A second area of high sand lance abundance shown by these data corresponds to the midshelf east of the Chesapeake, which was identified above as a region of high use by piscivorous cetaceans. It is likely that sand lance distributions are a primary controlling factor in the pattern of high-intensity habitat use shown here for the western Gulf of Maine.

Ammodytes is not the only cetacean prey species which can be shown to have a strong effect on patterns of cetacean habitat use within the western Gulf of Maine, although it is the major one. The right whale feeds primarily upon copepods (Nemoto 1970; Watkins and Schevill 1976). Right whales are a major component of the cetaceans in the southeasternmost portion of the high-use area in the western Gulf of Maine, in the vicinity of the Great South Channel, where they congregate in response to extremely dense spring concentrations of *Calanus finmarchicus* (CETAP 1982).

The other high-use cetacean habitat we have identified is the edge of the continental shelf. The cetacean assemblage of this region has been analyzed in detail by Hain et al. (1985). The primary species of the shelf edge are sperm whales, pilot whales, gray grampus, saddleback dolphins, bottlenose dolphins, and striped dolphins. Less common species include the various beaked whales and other dolphin species. This assemblage does not specialize on one or two prey species as we have suggested for the Gulf of Maine, but is highly diverse in prey taken, although individual species may exhibit quite narrow dietary specializations. Food items include a wide variety of squids and fishes (Kenney et al. 1985). Furthermore, the shelf edge assemblage on Georges Bank includes sei whales, which feed primarily on copepods and secondarily on euphausiids (Jonsgard and Darling 1977; Mitchell 1975a, 1975b; Nemoto 1970). Sei whales occur primarily on the southwest and eastern portions of Georges Bank. The CETAP data also show sightings of other baleen whales—primarily fin whales, but also minke, humpback, and right whales —near the southern edge of Georges Bank during some times of the year. The shelf edge, although used less intensely than the western Gulf of Maine, supports a cetacean fauna which is much more diverse in terms of both cetacean species and variety of prey taken.

We have interpreted our results in this study as indicating control of cetacean distributions by the distributions of the most important prey species. This is almost certain to be the case on a microscale level, but may or may not be true at the general level. It is unknown how migratory cetaceans orient or navigate to their feeding grounds, but it may be that physical cues from the environment are used in this process, in effect determining or influencing the general pattern of distribution. Another alternative could be that there is a significant traditional or historical component of the return to the same general vicinity each year, with microscale distributions within that region directly related to prey density. In each of these cases the ultimate controlling factor is food, but the proximate factors are something different.

We have limited our discussion of individual species mostly to the descriptive level. One factor, however, should be noted. Because we are dealing with biomass of cetaceans, these patterns are dominated by the large whales for the most part. Because fin whales are easily the most common whale in the region, they are the dominant factor in patterns of cetacean biomass distribution (Kenney et al. 1985; Scott et al. fn. 4). The most common species numerically were white-sided and saddleback dolphins, with estimated populations of each exceeding 30,000 individuals (CETAP 1982), but their contributions to the patterns shown here are smaller because of their relatively smaller sizes. One must refer to the distribution plots in the 1982 CETAP report for the details of individual species distribution patterns.

We have purposely avoided the use of the term "critical habitat" in this analysis. Besides the legal aspects of the term under the Endangered Species Act and Marine Mammal Protection Act, Ray and Miller[6] have pointed out that there are many dimensions to the concept of critical habitat. These include the biological vulnerability of a species, the ecological processes which support the species, and the poten-

[5]T. R. Azarovitz, Northeast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543, pers. commun. December 1982.

[6]Ray, G. C., and R. V. Miller. 1982. Critical habitats of marine mammals. Paper presented at 1982 annual meeting, International Council for the Exploration of the Seas, ICES C.M. 1982/N:7.

tial impacts of human activities. We have for the most part addressed only the patterns of habitat use, which contribute to the first two dimensions listed above. By giving extra weight to the endangered species in the Habitat Use Index, however, we have also further addressed the dimensions of biological vulnerability and potential impacts. On the other hand, the concept of critical habitat as strictly defined should be limited to single species. We have approached the problem from the viewpoint of the entire cetacean fauna of the region. Our analysis has defined those localities which appear to be important cetacean habitats based on the intensity of utilization with a special emphasis on the endangered species. These results now can and should be used as additional input for resource management and decision-making purposes.

ACKNOWLEDGMENTS

The preparation of this paper was made possible by funding from the Minerals Management Service, U.S. Department of the Interior, contract number 14-12-0001-30090. The CETAP study, which was the source of the data utilized, was funded by the Bureau of Land Management, contract number AA551-CT8-48. We would like to collectively acknowledge the many individuals who contributed to CETAP's success. G. B. Epstein developed the computer algorithm to measure track line surveyed per block, R. J. Medved provided statistical advice, and M. Nigrelli typed the manuscript. We are also grateful to K. Sherman, S. B. Saila, P. V. August, M. P. Sissenwine, G. T. Waring, and several reviewers at Minerals Management Service who provided helpful criticisms of early drafts of the paper. The work reported herein was part of a dissertation submitted by R. D. Kenney to the Graduate School of Oceanography, University of Rhode Island, in partial fulfillment of the requirements for the degree of Ph.D.

LITERATURE CITED

BURNHAM, K. P., D. R. ANDERSON, AND J. L. LAAKE.
1980. Estimation of density from line transect sampling of biological populations. Wildl. Monogr. 72:1-202.

CETACEAN AND TURTLE ASSESSMENT PROGRAM.
1982. A characterization of marine mammals and turtles in the Mid- and North-Atlantic areas of the U.S. outer continental shelf. Final report, contract AA551-CT8-48. Bureau of Land Management, Washington, DC.

FAGEN, R. M., AND D. Y. YOUNG.
1978. Temporal patterns of behavior: Durations, intervals, latencies, and sequences. *In* P. W. Colgan (editor), Quantitative ethology, p. 79-114. John Wiley & Sons, N.Y.

HAIN, J. H. W., G. R. CARTER, S. D. KRAUS, C. A. MAYO, AND H. E. WINN.
1982. Feeding behavior of the humpback whale, *Megaptera novaenglia*, in the western North Atlantic. Fish. Bull., U.S. 80:259-268.

HAIN, J. H. W., R. K. EDEL, H. E. HAYS, S. K. KATONA, AND J. D. ROANOWICZ.
1981. General distribution of cetaceans in the continental shelf waters of the northeastern United States. *In* CETAP, A characterization of marine mammals and turtles in the Mid- and North-Atlantic areas of the U.S. outer continental shelf, p. II.1-II.345. Annual report for 1979, contract AA551-CT8-48. Bureau of Land Management, Washington, DC. (Tables II-1, II-2, II-3.)

HAIN, J. H. W., M. A. M. HYMAN, R. D. KENNEY, AND H. E. WINN.
1985. The role of cetaceans in the shelf-edge region of the northeastern United States. Mar. Fish. Rev. 47(1):13-17.

JONSGARD, A., AND K. DARLING.
1977. On the biology of the eastern North Atlantic sei whale, *Balaenoptera borealis* Lesson. Rep. Int. Whaling Comm., Spec. Issue 1:124-129.

KENNEY, R. D., M. A. M. HYMAN, AND H. E. WINN.
1985. Calculation of standing stocks and energetic requirements of cetaceans of the northeast United States outer continental shelf. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NEC-41, 99 p. Northeast Fish. Cent. Woods Hole Lab., Natl. Mar. Fish. Serv., NOAA, Woods Hole, MA.

LOCKYER, C.
1981. Growth and energy budgets of large baleen whales from the Southern Hemisphere. *In* FAO Advisory Committee on Marine Resource Research, Mammals in the Sea, Vol. III, General papers and large cetaceans, p. 379-487. Food and Agriculture Organization of the United Nations, Rome.

MAYO, C. A.
1982. Observations of cetaceans: Cape Cod Bay and southern Stellwagen Bank, Massachusetts, 1975-1979. U.S. Mar. Mammal Comm., Rep. MMC-80/07, 75 p. [Available at National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151, as PB82-186263.]

MEYER, T. L., R. A. COOPER, AND R. W. LANGTON.
1979. Relative abundance, behavior, and food habits of the American sand lance, *Ammodytes americanus*, from the Gulf of Maine. Fish. Bull., U.S. 77:243-253.

MITCHELL, E.
1973. Draft report on humpback whales taken under special scientific permit by eastern Canadian land stations, 1969-71. Rep. Int. Whaling Comm. 23:138-154.
1975a. Preliminary report on Nova Scotia fishery for sei whales (*Balaenoptera borealis*). Rep. Int. Whaling Comm. 25:218-225.
1975b. Report of the meeting on smaller cetaceans, Montreal, April 1-11, 1974. J. Fish. Res. Board Can. 32:889-983.
1975c. Trophic relationships and competition for food in northwest Atlantic whales. Proc. Can. Soc. Zool. Ann. Meet. 1974, p. 123-133.

NEMOTO, T.
1970. Feeding pattern of baleen whales in the ocean. *In* J. H. Steele (editor), Marine food chains, p. 241-252. Oliver and Boyd, Edinb.

NISHIWAKI, M.
1972. General biology. *In* S. H. Ridgway (editor), Mammals of the sea, biology and medicine, p. 3-214. C. H. Thomas, Springfield, IL.

OVERHOLTZ, W. J., AND J. R. NICOLAS.
1979. Apparent feeding by the fin whale, *Balaenoptera*

physalus, and humpback whale, *Megaptera novaeangliae*, on the American sand lance, *Ammodytes americanus*, in the northwest Atlantic. Fish. Bull., U.S. 77:285-287.

SCOTT, G. P., AND J. R. GILBERT.
1982. Problems and progress in the U.S. BLM-sponsored CETAP surveys. Rep. Int. Whaling Comm. 32:587-600.

SERGEANT, D. E.
1969. Feeding rates of Cetacea. Fiskeridir. Skr. Ser. Havunders. 15:246-258.

SHERMAN, K., C. JONES, L. SULLIVAN, W. SMITH, P. BERRIEN, AND L. EJSYMONT.
1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature 291:486-489.

SMITH, G. J. D., AND D. E. GASKIN.
1974. The diet of harbor porpoises (*Phocoena phocoena* (L.)) in coastal waters of eastern Canada, with special reference to the Bay of Fundy. Can. J. Zool. 52:777-782.

WATKINS, W. A., AND W. E. SCHEVILL.
1976. Right whale feeding and baleen rattle. J. Mammal. 57: 58-66.

WATSON, L.
1981. Sea guide to whales of the world. E. P. Dutton, N.Y., 302 p.