Predicting Inshore Whale Abundance — Whales and Capelin off the Newfoundland Coast[1]

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Inshore abundance of baleen whales along the Newfoundland coasts changed considerably during the period 1973–83. In particular, large numbers of humpbacks were present along the northeast coast each summer between 1977 and 1980. This influx led to entrapment of whales in fishing gear. Counts of humpback (*Megaptera novaeangliae*), finback (*Balaenoptera physalus*), and minke (*Balaenoptera acutorostrata*) whales during standard surveys along the coast are used as indices of inshore abundance, and are related to the year-class strengths of capelin (*Mallotus villosus*), their major food in the Newfoundland region. Whales are found inshore when there are few immature capelin offshore. Minke whale distributions seem more closely related to the abundance of 1- to 2-yr-old, immature capelin, but humpback and finback whales are found inshore with low abundances of 2- to 3-yr-old, mainly immature capelin. We suggest that estimates of capelin year-class strength predicted from abiotic variables can be used to predict inshore whale abundance, at least 1 yr in advance. The extreme influx of humpbacks of the late 1970s is unlikely to recur in the short term. The analysis suggests that finback populations in the area are declining.

Le nombre de baleines à fanons dans les eaux côtières de Terre-Neuve a varié fortement de 1973 à 1983. En particulier, les rorquals à bosse étaient présents en grand nombres le long de la côte nord-est de 1977 à 1980, ce qui les amenaient à s'enchevêtrer dans les engins de pêche. Les dénombrements de rorqual à bosse (*Megaptera novaeangliae*), de rorqual commun (*Balaenoptera physalus*) et de petit rorqual (*Balaenoptera acutorostrata*) effectués au cours de levés normalisés le long de la côte sont utilisés comme indices de l'importance numérique en milieu côtier et sont mis en relation avec la biomasse des classes d'âge de capelan (*Mallotus villosus*), leur principale nourriture dans la région de Terre-Neuve. Les baleines fréquentent les eaux côtières quand il y a peu de capelans immatures dans les eaux hauturières. La répartition du petit rorqual semble étroitement liée à l'abondance de capelans immatures de 1 à 2 ans ; par contre, le rorqual à bosse et le rorqual commun occupent les eaux côtières quand le nombre de capelans de 2 à 3 ans, en grande partie immatures, est faible. Les auteurs formulent l'hypothèse que les estimations de la biomasse des classes d'âge de capelan extrapolées de variables abiotiques peuvent servir à calculer le nombre des baleines présentes dans les eaux côtières au moins 1 année à l'avance. L'abondance de rorquals à bosse signalée vers la fin des années 1970 ne se reproduira probablement pas à court terme. L'analyse porte à croire que les populations de rorqual commun sont en déclin dans cette région.

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During the summer months, humpback (*Megaptera novaeangliae*), finback (*Balaenoptera physalus*), and minke (*Balaenoptera acutorostrata*) whales are found off the Atlantic coast of Newfoundland, where they feed principally on capelin (*Mallotus villosus*) (Mitchell 1973, 1974a; Sergeant 1963). During the late 1970s the numbers of humpback whales along the northeast coast of Newfoundland in summer increased dramatically, and a large number of whales were entrapped in fishing gear, causing humpback mortality and considerable damage to the inshore fishermen (Lien 1981). In 1979, the worst year, 13 humpbacks died and the inshore fishery suffered about $2.5 million damage, approximately 2–3% of its total worth (Lien 1981). Since 1980, the situation has returned to pre-1977 levels, with relatively few whales inshore, and only moderate damage by whales to fishing gear.

Sergeant (1963) and Whitehead et al. (1980) presented evidence that the baleen whales change their geographic distributions, on a scale of days and weeks, in response to changing capelin abundance. Capelin were therefore a prime suspect in the search for a cause of the humpback influx of the late 1970s.

Capelin are small (approximately 13 cm) schooling fish. In the Newfoundland region they spawn on beaches or offshore

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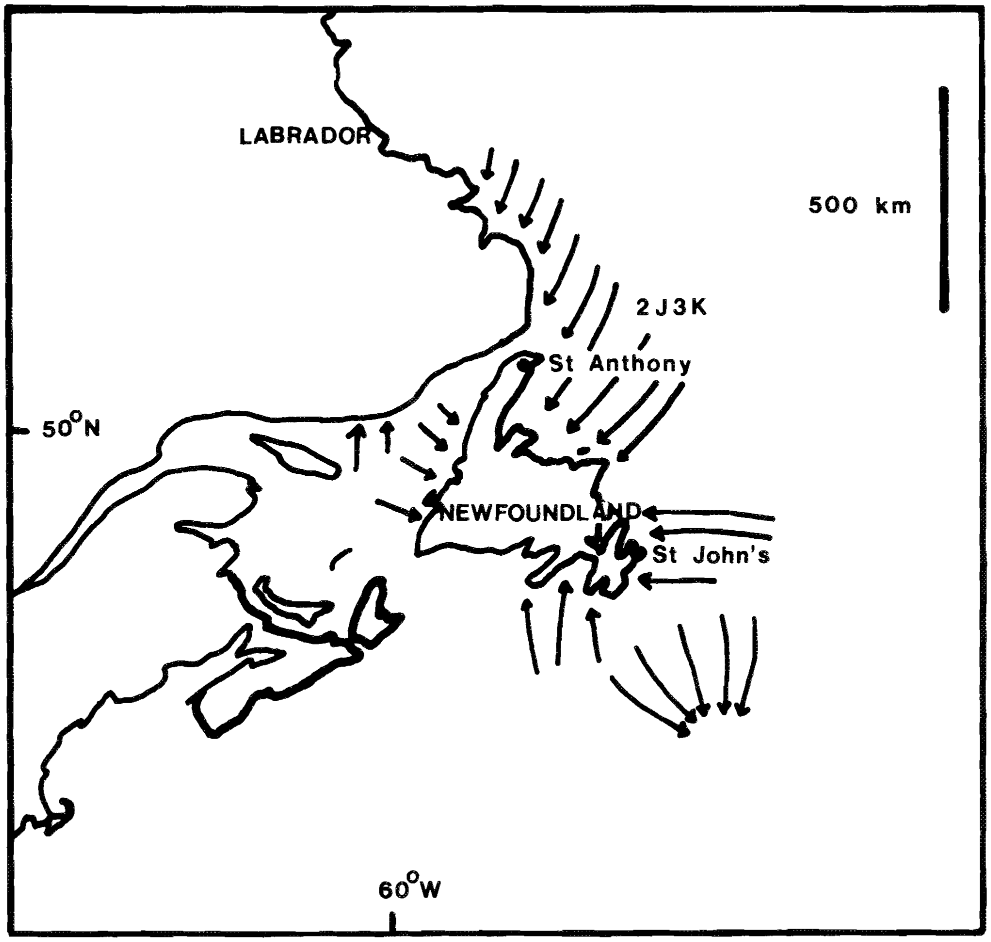

FIG. 1. Capelin stocks and spawning migrations in Newfoundland area, showing St John's and St Anthony, the endpoints of the northeast coast transects.

shoals during June and July. The larvae drift into deeper water, where the immature capelin feed before returning to shallow waters to spawn at 3–5 yr of age. Approximately 40% of 3-yr-old capelin, 50–70% of 4-yr-old capelin, and 93–100% of 5-yr-old capelin are mature, although these figures vary considerably with stock and year (Carscadden and Miller 1981; Carscadden et al. 1981). Very few capelin live beyond 5 yr of age.

Off Newfoundland, five major stocks of capelin (Fig. 1) have been identified (Carscadden 1983). Of these the stock northeast of Newfoundland and southern Labrador (NAFO areas 2J and 3K), which spawns along the northeast coast of Newfoundland and southern Labrador, appears to be the largest. The 2J3K stock also is represented by the longest time series of data, and since the stock area overlaps substantially with the location of the whale sightings used in this study, we chose it as an indicator of the status of the capelin stocks.

In this paper, the hypothesis that the abundance of whales inshore is related to capelin abundance was tested with correlation analysis using counts of whales along the northeast coast of Newfoundland and estimates of capelin year-class strength. The latter allowed a test of the relationship between whale abundance and the biomass of different ages of capelin. Predictive functions for whale abundance inshore were calculated, and used to investigate the probability of a return to the inshore humpback numbers of the late 1970s.

Methods

Between 1973 and 1983 (but excluding 1980) there have been a number of shipboard surveys of whales along the northeast coast of Newfoundland between St John's and St Anthony (Fig. 1). The route taken generally followed a path close to the shortest route between the two ports, although there was considerable variation. On each survey the observers included a professional and experienced cetologist. A count was made of the numbers of humpback, finback, and minke whales sighted on each survey (Table 1). A watch was kept for cetaceans throughout each survey, whatever the conditions. Sightings of whales made during halts or deviations from the survey route for the purposes of studying cetaceans were excluded from the counts. A variance-stabilizing square-root transformation was applied to both the counts and the mean counts over all surveys in any year.

Although the surveys between St John's and St Anthony were made from a variety of vessels (6-m sloop *Patience* to the large commercial ferry *William Carson*), at different times of year (15 July – 22 September), moving at various speeds, counts

TABLE 1. Mean annual counts of humpbacks, finback, and minke whales on surveys between St John's and St Anthony, with numbers of surveys for each year. Finback and minke counts were not available for one of the 1976 surveys.

Year	Number of surveys	Mean annual count		
		Humpbacks	Finbacks	Minkes
1973	1	0	13	3
1974	2	20	11	0.5
1975	1	17.5	11	1
1976	4	8.75	9.7	8.3
1977	2	54	9	10.5
1978	1	64	36	8
1979	1	111	20	5
1981	3	3	0.7	0.7
1982	1	10	0	10
1983	1	4	0	4
1984	1	0	1	3

within any year were reasonably consistent. There was significantly less variation between transformed humpback counts within a year than between years (F test, $P < 0.0005$). For finbacks and minkes, whose count showed less interyear variation, within-year and between-year variation did not differ significantly.

The transformed counts are compared with estimates of capelin year-class strength (as 2-yr-olds) from sequential cohort analysis of the 2J3K stock (Carscadden and Miller 1981) and predictions of year-class strength from abiotic variables from Leggett et al. (1983). (Similar predictions were obtained by Leggett et al. (1984), but because of a different statistical technique, slightly less efficient predictors were derived.) The capelin year-class strengths are logarithmically transformed, as in Leggett et al. (1983). For this analysis, it is assumed that the estimates of year-class strength of capelin at age 2 are indicative of relative year-class strengths for that cohort at all ages, even though natural mortality and spawning mortality undoubtedly vary annually. Different year-classes vary considerably, by over two orders of magnitude (e.g. Carscadden and Miller 1981), and an examination of available sampling data (J. E. Carscadden, unpubl. data) suggests that year-classes retain their relative strengths at all ages. Thus, it would appear that this assumption will not invalidate the analysis.

Results

Correlations between Whale Abundance and Capelin Year-Class

We calculated correlations between the northeast coast whale counts and the strengths of different aged year-classes (as estimated when 2 yr old) for capelin in the 2J3K stock (data as in Leggett et al. 1983). For instance, when comparing humpbacks and 3-yr-old capelin, the 1973 humpback count was compared with the strength of the 1970 year-class, the 1974 count with the 1971 year-class strength, etc. In Fig. 2 these correlations are shown plotted against capelin age for each whale species. The correlations present a fairly clear picture of the whales' responses to changing capelin year-class strengths.

The humpbacks appear to move offshore in response to strong year-classes of 3-yr-old capelin and to a lesser extent 2-yr-old capelin, but their inshore–offshore movement does not seem closely related to the abundance of 1- or 5-yr-old capelin. Figure 3 shows mean inshore humpback counts plotted against estimated 3-yr-old capelin biomass.

Finbacks also move offshore in response to high abundance of 2- to 3-yr-old capelin. There is an additional tendency for finbacks to move inshore when there are many 5-yr-old capelin. These 5-yr-old capelin are mature and will be spawning along the coast.

The minkes' response to varying year-class strengths presents a substantially different picture from that for humpbacks or finbacks. Minkes move offshore in response to high abundance of 1- to 2-yr-old capelin, but their distributions seem less related to the 3- to 5-yr-old year-classes.

Some caution must be exercised when attempting to derive biological relationships from correlation analysis. For instance, it is tempting to suggest that finbacks move inshore when abundance of young capelin is low. At the same time, the positive (though not significant) correlation between 5-yr-olds and finbacks suggests that the whales move inshore when this age-class is large. However, these events may be occurring at the same time; in any given year, when the abundance of finbacks inshore is high, it is possible that the abundance of immature capelin offshore is low, and mature 5-yr-olds is relatively high. To properly evaluate the possible biological relationships, a detailed multivariate analysis of many more years data would be necessary. However, the present correlation analysis does identify possible biological relationships which can be used to formulate hypotheses concerning species relationships.

Changing Whale Populations

Correlations between the northeast coast whale counts and year were calculated for each species in order to investigate whether there were significant overall increases or decreases in whale abundance over the period of the surveys. The only significant correlation was that for finbacks ($r = -0.635$, $P < 0.05$), whose numbers apparently decreased significantly between 1973 and 1983. This decline in finback abundance is borne out by a more comprehensive analysis of whale sightings over the entire Newfoundland area (Lynch and Whitehead 1984).

Predicting Whale Abundance

Unfortunately, there are no reliable direct estimates of capelin year-class strength after 1978, as this was the last year when there was a large enough fishery to obtain adequate samples for reliable assessment (Leggett et al. 1983). However, Leggett et al. (1983) have shown that capelin year-class strengths off Newfoundland can be predicted from a knowledge of mean spawning date and the abiotic variables WIND (a measure of the extent of unfavourable wind conditions during the period in which the larval capelin drift away from the spawning beaches) and TEMPSUM (a measure of seawater temperature during the months after spawning), taken from standard meteorological records. For the 2J3K stock their model has an r^2 of 0.73.

Stepwise multiple regressions of whale counts on year, and capelin year-class strength, as predicted by Leggett et al. (1983), were made. The results (Table 2) show that the estimated strengths of the 2- and 3-yr-old year-classes are excellent predictors of inshore humpback abundance. For finbacks the 3-yr-old year-class strength and year are also excellent pre-

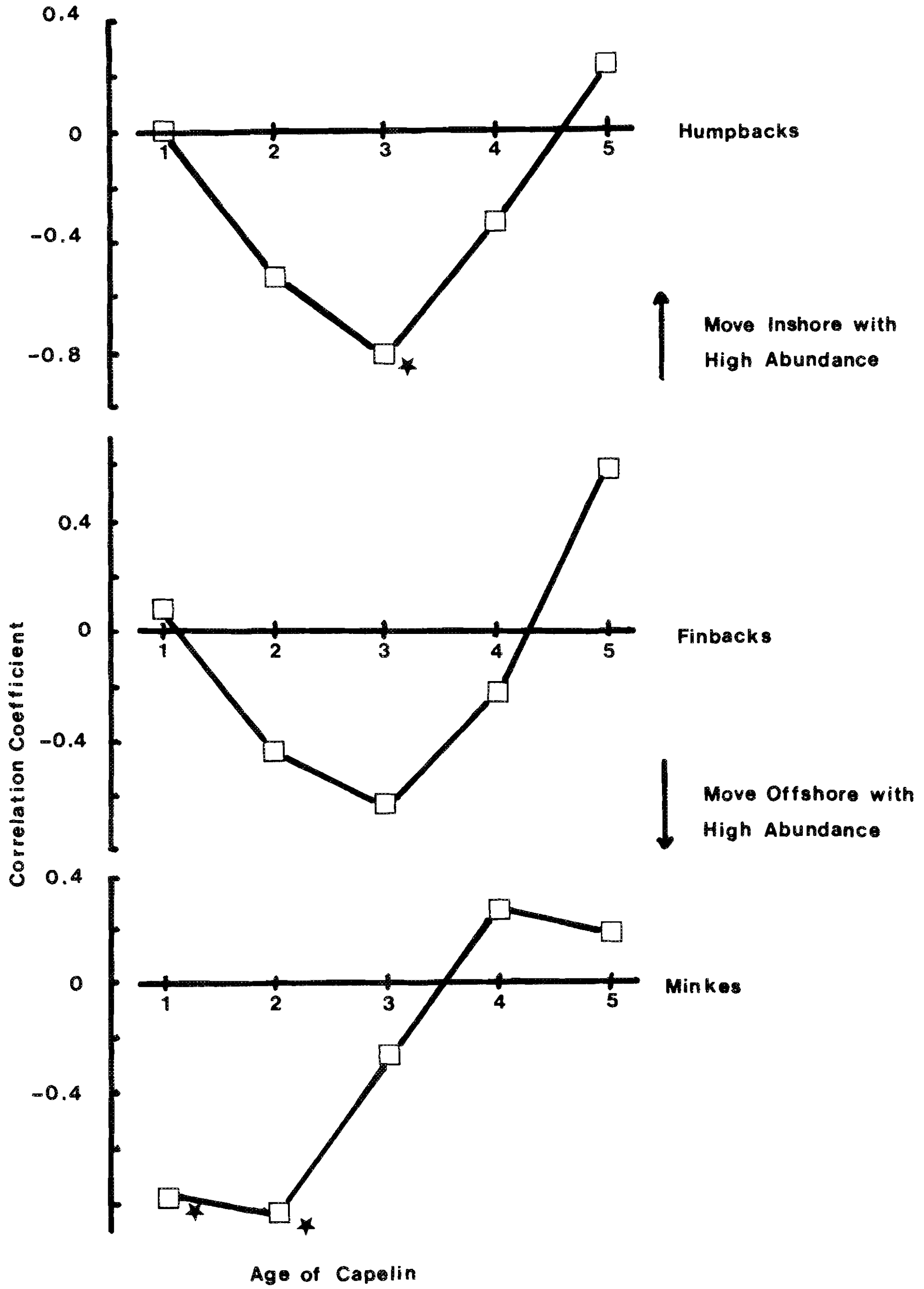

FIG. 2. Correlation coefficients between northeast coast whale counts and the strength of different aged year-classes of capelin in stock 2J3K. ★, correlations significant at $P < 0.05$.

dictors. Minke abundance is much less well predicted by these variables.

Thus, it seems that humpback and finback whale abundances on the northeast coast of Newfoundland can be predicted with reasonable accuracy, at least 1 yr in advance, using year-class strengths of capelin predicted from abiotic variables as in Leggett et al. (1983).

Extreme Years

The extreme abundance of humpback whales inshore during the late 1970s inflicted considerable hardship on the fishermen of Newfoundland. The regression given in Table 2 allows us to predict the probabilities of similar humpback densities occurring in the future. Assuming no correlation between adjacent capelin year-classes (there was no significant autocorrelation in the data presented by Leggett et al. (1983)), we calculated the probability of inshore abundances as large as, or larger than, those in the late 1970s (Table 3). If overall humpback and capelin populations do not change considerably, we can expect inshore humpback densities as high as, or higher than, in 1977 (54 humpbacks counted) once every 7 yr, in 1978 (64 humpbacks counted) once every 11 yr, and 1979 (111 humpbacks counted) once every 125 yr.

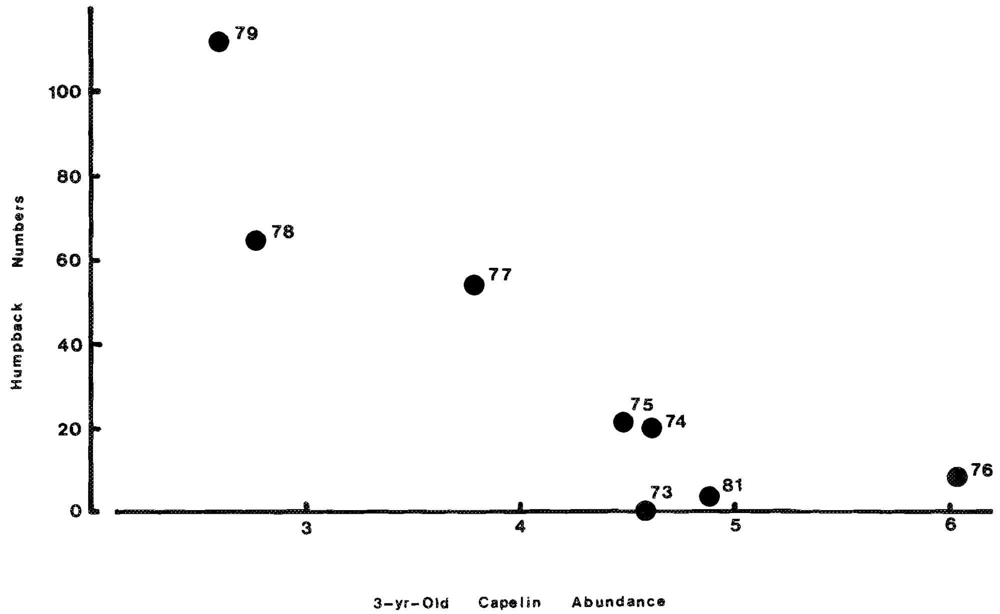

FIG. 3. Counts of humpback whales along the northeast coast of Newfoundland plotted against 3-yr-old capelin abundance in stock 2J3K (logarithmically transformed).

TABLE 2. Results of stepwise multiple regressions of northeast coast whale counts on year, and on estimated strength of year-class of different aged capelin from Leggett et al. (1983), for stock 2J3K. JK1 = 1-yr-old capelin in stock 2J3K, etc. The first three independent variables entered in each regression, their coefficients (after three variables had been entered), and values of r^2 at each step are given. Coefficients significantly different from zero: $*P <$ 0.05; $**P < 0.01$. These regressions may be used to predict inshore whale abundance.

Dependent variable	Order entered in regression (coefficient/r^2)		
	1	2	3
Humpback	JK3 (−2.31**/0.61)	JK2 (−1.25*/0.80)	JK1 (0.92/0.88)
Finback	JK3 (−1.01**/0.46)	Year (−0.45**/0.79)	JK4 (−0.72/0.89)
Minke	JK2 (−0.71*/0.63)	Year (0.09/0.67)	JK1 (−0.24/0.73)

TABLE 3. Probabilities of counting more humpbacks along the northeast coast than in the extreme years of 1977, 1978, and 1979. Calculations use the regressions in Table 3, with the first two variables entered in the regression (2- and 3-yr-old capelin).

Year	Humpbacks counted	Probability that more humpbacks are counted
1977	54	0.14
1978	64	0.089
1979	111	0.008

Discussion

The predictors of humpback abundance inshore which have been obtained in this paper should be of considerable importance in the forecasting of entrapment damage to fishing gear in the short term. They will allow fishermen to be warned, at least 1 yr in advance, if severe entrapment problems are anticipated, and permit extensive whale release programs and other alleviating measures to be established.

This analysis also shows the range of variation in humpback abundance, and whale damage, that might be expected over the longer term (e.g. greater than 10 yr). This information is potentially valuable when deciding the general level of services, and the infrastructure, that are needed to deal with the whale entrapment problem. It also allows prediction of mean whale mortality from entrapment, important when considering the population dynamics of the whale stocks.

Extrapolations of these results over periods longer than 10 yr or so should be used cautiously: the absolute populations of the whales could change, and there might be significant variation in the general oceanography of the area which could in turn affect the population dynamics of both predators and prey. It is important that the oceanography, capelin abundance, and whale numbers continue to be monitored as systematically as possible.

What happened during the late 1970s when there was such a profusion of whales inshore? This analysis shows that the appearance of the whales was probably a natural consequence of changes in the status of the capelin stock. The late 1970s was a period of exceptionally low capelin abundance. This decline in the stock closely followed the development of the capelin fishery off Newfoundland during the mid-1970s. However, the fishery took only an apparently insignificant part of the available biomass, and Leggett et al. (1983) argued that the low abundance was largely due to an unfavourable combination of environmental variables.

Whitehead and Lien (1982) have shown that the changes in whale abundance on different parts of the Newfoundland coast were not synchronous. While whale numbers at different locations along the northeast coast changed more or less in step, sighting and entrapment rates on both the south coast and off southern Labrador were out of phase with the northeast coast counts given in this paper. On the south coast, humpback sightings peaked in 1977, whereas off southern Labrador they increased during the early 1980s. A more fine-scale version of the analysis presented here might illuminate these variations, but there are not sufficient data on capelin on the south coast to describe the population dynamics of that stock. Additionally, humpback and finback whales make considerable migrations, crossing several NAFO areas during the summer (Mitchell 1974a; Whitehead et al. 1982). Thus, the presence of a whale inshore in a particular area might be a response to the lack of immature capelin in a stock which spawns in a different area. In this respect the 2J3K stock, the largest in the western North Atlantic, could have great significance in determining inshore whale distributions over the entire region.

For the humpbacks, at least, mature spawning capelin seem to be a secondary food source, generally used only when there are few immature capelin. This might be on account of the proximity to shore of the mature capelin, or some function of their schooling behaviour.

An interesting by-product of the analysis is the suggestion that minke whales may be generally eating younger capelin than humpbacks and finbacks. There has been some concern about possible trophic competition between baleen whale species off eastern Canada (Mitchell 1974b), and competition might be involved in the apparent recent decline in finback numbers (Lynch and Whitehead 1984). The kind of analysis performed here is one method of obtaining information on such competition.

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