RESTRICTED

International Commission for the Northwest Atlantic Fisheries

Serial No. 3256
(D.c.3)

ICNAF Res.Doc. 74/49

ANNUAL MEETING - JUNE 1974

Modified Leslie-DeLury assessments of the Northern Pilot Whale (Globicephala melaena) and annual production of the Short-finned Squid (Illex illecebrosus) based upon their interaction at Newfoundland[1]

by

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Introduction

Both Globicephala melaena and Illex illecebrosus are seasonal migrants to Newfoundland inshore waters, the two arriving and departing almost simultaneously and the former feeding almost exclusively on the latter. Availability of both species inshore has been sporadic and fisheries for both have shown wide fluctuations in landings. Does the abundance of whales inshore correlate with that of squid and if so does the recent collapse of the pilot whale fishery relate to dearth of squid inshore and/or to overexploitation of the whale stocks? What can be deduced regarding population sizes of each through a study of their interaction?

Sergeant (1962) has ascribed the decline in whale landings in years immediately subsequent to 1956 principally to hydrographic factors (these being taken to reduce availability of squid inshore) while, in assessing a much longer series of landings data, Mitchell (1974) considered that the fishery severely depleted the stocks, this assumption being the basis of his estimate of initial population size from a cumulative catch plot.

Recent estimates of the standing stock of Illex illecebrosus have ranged to hundreds of thousands of tons (Gulland, 1972; Voss, 1973); however, these estimates are guesses rather than being derived from any detailed assessment of the resource.

This paper reviews distribution, seasonal abundance and trophic relations of the two species, describes the fisheries and assesses correlations between landings. The implications of these correlations are discussed and utilized in the estimation of stock size of the whale and annual production of the squid.

[1]Based on document M8 presented to the Subcommittee on Small Cetacea of the Scientific Committee of the International Whaling Commission, Montreal, April 1-12, 1974.

Distribution

Geographic ranges

Northern Pilot Whale. This cetacean is recorded from Iceland (Saemundsson, 1939) and Greenland (Brown, 1868; Jensen, 1928; Sergeant, 1968) southward to New England. The only positive G. melaena from New Jersey are two specimens examined by Ulmer (1961). A single extralimital stranding was noted from Virginia (Paradiso, 1958). Recently McGrath and Thomas (1973) listed records from Assateague Island, Virginia, Nags Head, North Carolina and Grassy Key, Florida; pending verification it must be considered that these could have related to G. macrorhyncha, a species which did not occur in their long list of sightings and strandings. Davies' (1960) distribution map indicates an eastern Atlantic range extending from the Barents Sea to northwest Africa. The species apparently has a continuous distribution across the deep waters of the North Atlantic (Brown, 1961).

Short-finned Squid. While the short-finned squid has also been recorded at West Greenland (Posselt, 1898) and Iceland (Gröndal, 1891) there are no published twentieth century records of the species there and reported occurrences require confirmation (Mercer, 1968). The species does range at least from Labrador (Squires, 1957) to Florida (Roper, Lu and Mangold, 1969) and it occurs southwards to the area of the Bristol Channel in the eastern Atlantic (Adam, 1952). Published records extend from coastal waters to the area of the continental slope with no mid-ocean captures having been noted.

Comparison. While the distribution of the whale and squid are thus broadly confluent that of the former appears less restricted by depth so that the two are not sympatric in the oceanic zone. Both have the most northerly distributions of species in their respective genera and both are replaced by congeners to the south, by G. macrorhyncha in the case of the pilot whale and I. oxygonius and I. coindeti in the case of the short-finned squid.

Seasonal movements

Northern Pilot Whale. Globicephala melaena shows marked seasonal variation in its distribution. The earliest recorded arrival date on the Grand Bank is June 27 both in 1953 and 1954 and the whales remain there up to late autumn; an exceptionally late sighting occurred in early January, 1953 (Sergeant and Fisher, 1957).

The earliest record from Newfoundland coastal waters noted by Sergeant and Fisher (1957) was June 26, 1954, and the latest sighting in Trinity Bay during the period 1951-55 was on November 10, 1954. Mercer (1967) also noted a single sighting of a herd in Trinity Bay in January, 1951, and sightings in January and the capture by driving on February 14 of a herd in Trinity Bay in 1967.

Pilot whales are not commonly seen in inshore waters of the Maritime Provinces of Canada or southwards although some sightings and strandings have been recorded (Sergeant and Fisher, 1957; Sergeant, Mansfield and Beck, 1970).

Summer sightings offshore are widespread off New England (Sergeant, unpublished), Nova Scotia (Mercer, 1973a), in the Labrador Sea (Sergeant and Fisher, 1957) and over oceanic depths east of the Grand Bank (Brown, 1961; Sergeant and Fisher, 1957). Three winter (December to March) sightings have been made off New England (39°42'-41°00'N, 70°25'-70°53'W; Mercer, 1967) a single overwintering was reported near Godthaab, Greenland (Jensen, 1939) and winter records have been noted east of the Grand Bank (Brown, 1961; Sergeant and Fisher, 1957). While stock relationships of northwest Atlantic pilot whales are not known, Sergeant (1962) has suggested that the main wintering area of the stock fished at Newfoundland is in the waters of the North Atlantic Current, east of the Grand Bank.

Short-finned Squid. Illex illecebrosus is a highly migratory species. It is rarely taken in Canadian Atlantic waters during the winter months and first appears in abundance on the continental shelf in May and June (Squires, 1957). Populations visiting Newfoundland inshore waters approach from the south and are taken on the southwestern part of the Grand Bank and on the southern part of St. Pierre Bank in spring prior to reaching the inshore area (Squires, 1957, 1959; Mercer, 1966, 1973b).

Occurrence inshore is generally from July to October or November with outer limits of mid-June to early December. Even during this period squid are known to occur on the continental shelf offshore (Nielsen, 1891; Squires, 1957). It has been suggested that spawning and subsequent death occur during winter months in waters to the south; however, the relationships of stocks of the species known to occur in winter off the coast of the United States (Mercer, 1969a, 1970a) have not yet been described.

Comparison. It is evident that spring arrival of the whales is somewhat later than is that of squid on the Grand Bank. Sergeant and Fisher (1957) suggested that this may be because the squid are in deeper water in May and June. Recent studies by Mercer (1973b) have indicated that, in this period, squid concentrate at the edge of the continental shelf in waters generally warmer than 5°C when vertical dispersal and horizontal movement to shallower areas on the shelf are impeded by overlying cold arctic water. The only winter sighting of pilot whales on the Grand Bank (January, 1953) was associated with an unusually late occurrence of squid in the area in a year of marked Gulf Stream influence (Sergeant and Fisher, 1957).

Occurrences of both species inshore are nearly coincident with the whales arriving shortly after the squid and, aside from a few winter records, departing slightly before the last of the squid. It is only in the Newfoundland area of the Northwest Atlantic that inshore migrations of both species are regular events.

Trophic Relations

Diet of the Northern Pilot Whale

An explanation of the congruences observed in seasonal migrations, particularly to eastern Newfoundland waters, can be seen in the diet of the pilot whale. In observations at Newfoundland from 1951 through 1956 no food items were observed except short-finned squid (Sergeant, 1962). In late August, 1957, squid rapidly disappeared from inshore areas and they were followed by a majority of the pilot whales; those remaining were reported to be feeding on cod (*Gadus morhua*). In 1958 squid were scarce inshore and few pilot whales were taken, these again being reported as feeding on cod (Sergeant, 1962). Whale stomachs examined early in the 1959 season contained squid with a small proportion of cod (Sergeant, 1962). Aldrich and Bradbury (unpublished) reported beaks of both *Gonatus fabricii* and *Illex illecebrosus* in their examination of stomachs of 12 pilot whales at Chapel Arm, Trinity Bay (in the late 1960's). The one herd driven in winter was found to have been feeding on the Greenland turbot (*Reinhardtius hippoglossoides*)(Mercer, 1967). A reported instance of feeding on long-finned squid (*Loligo pealei*) in the Gulf of St. Lawrence (Préfontaine, 1930) has been shown to have resulted from misidentification of the short-finned squid (Mercer, 1970b).

It is evident then that squid is the preferred diet of pilot whales in the Newfoundland area with fish being taken as an alternative only when squid are not available.

Feeding rate of the Northern Pilot Whale

From stomach contents examined at Newfoundland Sergeant (1962) stated that an average-sized pilot whale 13 ft (396 cm) long and weighing about 1830 lb (830 kg) appears to require 25 to 30 lb (11 to 14 kg) of food to fill its stomach. Limited observations indicated a digestion time of less than 8 hours so that daily average consumption from 3 meals could total 75 to 90 lb (34 to 41 kg). This is equivalent to a feeding rate of 4.1 to 4.9 per cent of body weight per day and an annual consumption of 12,410 to 14,965 kg or 15.0 to 18.0 times body weight per year.

As reviewed by Sergeant (1969) the feeding rates of *G. scammoni* observed in captivity (Brown, 1960, 1962; Gilmore, 1962) were in the order of 4.0 to 5.9 per cent of body weight per day. Thus the estimates for *G. melaena* above do not appear to be inordinately high.

Newfoundland Fisheries

Northern Pilot Whale

According to Templeman (1966) there has been a small amount of exploitation of pilot whales at Newfoundland for several centuries, by the whalers before 1900 and by fishermen who drove herds ashore and utilized those which stranded naturally. The modern industry began in 1947 at Dildo, Trinity Bay, when a factory was established and two small catchers started harpooning pilot, minke and a few large whales (Sergeant, 1953). From 1951 on nearly all pilot whales were taken by driving with a variable number of animals, generally only a few hundred annually, being harpooned from the catcher vessels when circumstances made driving impossible (Sergeant, 1962). While most of the pilot whales landed were taken in Trinity Bay large numbers were also captured in Bonavista Bay and a few in

Notre Dame Bay (Sergeant, 1962). Landings fluctuated considerably, reaching a peak of 9799 in 1956 and lower peaks in 1961 and 1964. The fishery ended when commercial whaling on the Canadian Atlantic coast was banned by the Government of Canada on December 22, 1972.

Short-finned Squid

A trawl fishery for squid developed in the area of Mid-Atlantic Bight off the coast of the United States beginning in 1968. While this fishery is primarily for the long-finned squid (Loligo pealei) a small but indeterminate part of the catch comprises short-finned squid taken both as a by-catch and, more recently, as a result of limited directed fishing (Mercer, 1973c). Squid taken on the continental shelf in the Canadian Atlantic are all short-finned squid. Landings reported 1971 to 1973 were 7284, 1842 and 7963 metric tons; no figures are available for earlier years.

The species has historically supported summer and fall inshore fisheries at the northern extreme of its western Atlantic range particularly at Newfoundland where recent annual landings have ranged from 1 to 10,500 metric tons. While the fishery probably dates back to the days of first settlement and the early cod fisheries, statistics on landings are available only for recent years. Squires (1957) collated data from various sources and presented a histogram of relative annual abundance for the period 1879 to 1954. Total landings are available in the "Fisheries Statistics of Canada" beginning in 1952. A breakdown by area is also available for 1955 to 1968 and by month for 1956 to present; these data have been recently summarized (Mercer, 1973c).

The Newfoundland fishery is passive in that it is based on availability of squid to jigging devices in inshore waters of less than about 20 metres depth and fluctuations in catch reflect variations in local distribution in relation to environmental parameters and variation in behaviour with regard to jigs (Mercer, 1971). Jigs traditionally employed were single painted lead lures bearing a circlet of barbless hooks. However, beginning in 1964, mechanized Japanese jigging devices were introduced (Quigley, 1964) and these quickly supplanted traditional jiggers. When squid are abundant these devices allow a several-fold increase in catch per man-hour. A few stationary traps have also been employed on the southeast coast but these account for a very small proportion of total landings.

Unfortunately no measure of effort is available for the inshore fishery and, in employing landings as a measure of availability of squid inshore, one cannot adjust for changes in effort or gear efficiency.

Correlations

From knowledge of the trophic relations between the two species one would hypothesize a correlation between availability of whales inshore and that of squid and, if effort expended in both fisheries were constant, the correlation would be expected in catch figures. Correlation coefficients relating whale landings to those of squid were calculated for various periods 1952-1972 (Table 1) and the ones associated with significant probability values were those for longer periods. (The one-sided test is appropriate as a positive correlation was expected by prior hypothesis). The trophic relation between the species indicates the causal basis of the correlation.

Taking the assumptions above and even assuming that squid abundance is the sole determinant of pilot whale abundance inshore then a perfect correlation between catch figures could only obtain if the fisheries did not deplete either stock. Comparison of graphs of landings indicates otherwise (Fig. 1). Peaks in pilot whale landings in 1956, 1961 and 1964 show a declining trend and, while peaks in squid landings coincide in time, the opposite trend obtains with highest landings being made in 1964. This is interpreted to indicate depletion of the pilot whale stocks, an argument which will be further developed in the following section.

Assessments

Stock size of the Northern Pilot Whale

The foregoing correlation can now be utilized in developing models to estimate the initial stock size of pilot whales fished at Newfoundland. Let us assume that for the periods being considered:

1. The effort expended by whale catchers and their efficiency have remained constant.

2. The effort expended on squid has remained constant.

3. The catches of both species are accurate measures of abundance inshore.

4. There is a positive correlation between abundance (as measured by landings) of the two species in the fishing area and remaining variation in whale abundance (landings) not explained by this correlation is random.

5. No stocks of pilot whales have moved in to occupy grounds formerly occupied by extinct stocks and no emigration has occurred of stocks formerly exploited at Newfoundland.

6. Recruitment and natural mortality of pilot whales have remained in balance as in the virgin stocks.

Closed-system models patterned after those developed by Leslie and Davis (1939) and DeLury (1947, 1951) can then be generated. The following notation is adopted:

t designates the t^{th} year

d_t relative rate at which individuals are removed from the whale population by whaling

c_t number of whales taken in year t

e_t whaling effort in t^{th} year, taken to be constant from year to year

a_t catch of squid in year t, a correction factor for availability of whales

$A_t = a_1 + a_2 + \ldots a_{t-1}$ the total squid catch up to the start of year t

$C_t = c_t/e_t$ the catch of whales per unit of effort in year t

$K_t = c_1 + c_2 + \ldots c_{t-1}$ the total whale catch up to the start of year t

$E_t = e_1 + e_2 + \ldots e_{t-1}$ the total whaling effort up to the start of year t

k_t catchability of whales during year t, i.e. the proportion of the whale population taken per unit of effort

N_t size of the whale population at the start of year t

$N = N_1$ whale population size at the beginning of the sampling period when $K_t = E_t = 0$

<u>Model I</u>. From the definitions

$C_t = k_t N_t$, if units of effort do not compete. (1)

In the DeLury model one would now designate $k_t = k$, a constant throughout the sampling period. The present model requires a correction for availability, a parameter which has been shown to be correlated with squid abundance.

$k_t \propto a_t$

Let D be the constant of proportionality

Then $k_t = Da_t$

or $D = k_t/a_t$

Since the population is considered to be closed then

$N_t = N-K_t$

So that the equation (1) can be re-written

$C_t = Da_tN-Da_tK_t$ or

$$\frac{C_t}{a_t} = DN-DK_t \qquad (2)$$

If the assumptions hold then a plot of the values of C_t/a_t against those of K_t yields a straight line with intercept DN and slope-D from which N can be calculated by simple division.

Model II. Since we assume no net additions to or subtractions from the population, except by fishing, the net change in population size in the interval (t, t + dt) is given by

$N_t[-d_t]dt$ which may be equated to $N(t + dt)-N_t$

Dividing by dt and passing to the limit as dt approaches zero

$$\frac{dN_t}{dt} = N_t - d_t \text{ or}$$

$$\frac{d}{dt}\ln N_t = -d_t \qquad (3)$$

Now $d_t = k_t e_t$ by assumption

and $k_t = Da_t$ as demonstrated in Model I

$\therefore\ d_t = Da_t e_t$

Under the given assumptions (3) becomes

$$\frac{d}{dt}\ln N_t = -Da_t e_t$$

which upon integration gives

$$\ln N_t - \ln N_o = -De_t \int_o^t a_t dt = -De_t A_t$$

which can be written

$$N_t = -De_t N_o - De_t A_t \qquad (4)$$

from either (3) or (4) it follows that

$$\frac{dN}{dE} = -De_t N_o e^{-De_t A_t}$$

by assumption

$$\frac{dN}{dE} = -C_t$$

$$\therefore\ C_t = De_t N_o e^{-De_t A_t}$$

$$\frac{C_t}{a_t} = \frac{De_t N_o e^{-De_t A_t}}{a_t}$$

$$\ln[\frac{C_t}{a_t}] = \frac{\ln De_t N_o}{\ln a_t} - \frac{De_t A_t}{\ln a_t}$$

If a plot of $\ln\frac{C_t}{a_t}$ against A_t gives a straight line the intercept is

$\frac{\ln De_t N_o}{\ln a_t}$ and the slope $\frac{-De_t}{\ln a_t}$ from which N_o can be derived.

Model III. This model can be generated after Sandeman (1969) as follows:

$$N_t = N_o - \sum_1^t c_t \qquad (5)$$

The instantaneous decrease of the population is proportional to the number present.

$$\frac{dN}{dt} = -qN$$

which yields on integration

$$N_t = N_o e^{-qt} \qquad (6)$$

Thus from (5) and (6)

$$N_o - \sum_1^t c_t = N_o e^{-qt}$$

$$\text{or } \sum_1^t c_t = N_o(1-e^{-qt})$$

Thence by substituting t + 1 for t and subtracting the resulting equation from it

$$\sum_1^{t+1} c_t = N_o(1-e^{-q}) + \sum_1^t c_t e^{-q} \qquad (7)$$

With N and q constants a plot of $\sum_1^{t+1} c_t$ versus $\sum_1^t c_t$ yields a straight line with intercept $N_o(1-e^{-q})$ and slope e^{-q} from which N can be calculated.

Results. Since the assumptions underlying the closed-system models do not permit net change in population size except through fishing the minimum allowable estimate of initial population size must exceed the cumulative catch; for the period 1947 to 1971 this was 54,348.

Population estimates derived from Model I vary between 66,273 and 99,183 for the start of the 1947 fishery (Table 2). Elimination of values derived from poorly fitted lines ($P > .10$) yields estimates of 66,273 and 75,361 with a mean of 70,817.

Estimates derived from Model II are 49,142 to 54,806 with a mean of 52,618 while those from Model III are 62,516 to 79,592 with a mean of 69,926. The overall mean estimate derived from all well-fitted ($P < 0.10$) lines in the three models is 62,432.

Discussion. Studies were undertaken by Sergeant in 1957, following the record catch in the previous year, to determine whether any changes had taken place in the composition of the herds and in the growth rates and reproductive frequency of the population which might indicate a population decline; while no such changes were found (Sergeant, 1962) such density-dependent responses would be expected to require a longer period in a species with a long generation time.

Since hunting is almost completely non-selective, except for a small amount of selective harpooning (Sergeant, 1962), two usual criteria of the degree of fishing pressure - the increase in total mortality at ages fished commercially and the reduction in size of the average animal killed are not available for the pilot whale (Templeman, 1966). Sergeant (1962) has suggested that a lowering of population levels by hunting could allow a decline in natural mortality rates; however, only one estimate of natural mortality has been made (for 1954).

Mitchell (1974) had a larger series of catch data available than did Sergeant (1962) and considered that the stock fished at Newfoundland was severely depleted by the fishery. He used the cumulative catch of 47,078 in 1951 to 1961 to estimate an initial population size of about 50,000 which is slightly lower than the mean estimate presented here.

The robustness of the foregoing models should be studied with respect to errors introduced by possible trends, or abrupt shifts, in parameters introduced as constants in the assumptions. One possible error relates to the introduction of mechanized squid jiggers in 1964. The increase in gear efficiency, other factors being equal, would result a higher squid catch in relation to the squid stock available. This would cause an overestimate of availability of whales and be equivalent in the models to a decrease in catchability. Braaten (1969) has indicated that a decrease in catchability results in a decrease in the estimate of initial population size. The lower estimate in each set is that including post-1964 data (Table 2), this being consistent with the presence of the foregoing bias.

The models assume that no trends exist in recruitment and natural mortality and that there is no net emigration or immigration. Such constraints disallow the possibility of recovery of a depleted population and as such would not be expected to apply in nature. In response to heavy exploitation one could anticipate an increase in recruitment through earlier maturation and higher pregnancy rates, a decrease in natural mortality and net immigration from contiguous stocks. Holding these parameters constant in the models would have the effect of producing an upward bias in the estimate of initial population size. In the absence of recent estimates of the population parameters involved it is intended to expand the models to incorporate a range of possible correction factors. In the meantime it should be considered that the values generated are high and that the initial population size was probably less than 60,000.

While the source of this population is unknown there is presently no evidence of other than local depletion. If Sergeant (1962) is correct in his suggestion of a wintering area east of Newfoundland it may be that populations near Greenland, south of Newfoundland to New England and in the central and eastern Atlantic have not been affected by the Newfoundland fishery and are not counted in the above estimates.

Annual production of the Short-finned Squid

Calculations. The amounts of squid consumed in the approximately 100-day season inshore and throughout the year for a range of initial stock sizes of the pilot whale have been calculated, based upon a single species diet for pilot whales and the range of feeding rates discussed earlier in this paper (Table 3). Consumption estimates for the 100-day season are 166,000 to 249,000 metric tons for an initial population of 50,000 whales; annual consumption for this population is estimated at 605,900 to 908,850 metric tons. Higher estimates are generated in utilizing higher initial population estimates (Table 3).

Discussion. It is thought that the species has a one-year life-span and dies after spawning (Squires, 1967). If this is the case then an estimate of annual production relates simply to stock size.

It is important to evaluate the constraints relating to the foregoing estimates. The consumption estimate for the 100-day season assumes that the entire whale stock is feeding exclusively on squid. While this condition generally appears to be fulfilled for pilot whales inshore, only part of the whale population is available inshore in any given season; the estimate thus assumes that the remaining whales are also feeding on squid. The congruence in seasonal distributions of the two species on the continental shelf near Newfoundland supports this assumption but it has not been tested by empirical observation.

The validity of extrapolation to estimate annual consumption is subject to the reservations introduced in discussion of the wintering areas of the pilot whales involved. If the species is feeding pelagically in winter in the warm waters of the North Atlantic Drift east of Newfoundland then *Illex illecebrosus* would not be expected to be available to it; the diet might then be oceanic squids (including other species of ommastrephids) and oceanic fishes.

Reservations discussed in the foregoing two paragraphs thus indicate likely sources of high bias in the consumption estimates. Other constraints to the analysis introduce low bias.

While heterogeneity has been found in mantle length compositions of short-finned squid sampled at Newfoundland, it has been suggested that a single year-class only is present and the heterogeneity has been suggested to relate possibly to a protracted spawning season and area (Mercer, 1969b). The heterogeneity observed between areas inshore (Mercer, 1969b) and on the continental shelf (Mercer, 1973b) indicates that pilot whales feeding at southeastern Newfoundland are sampling only that part of the squid population comprising larger, more northward-migrating animals. Squid on the Newfoundland south coast, inshore at Nova Scotia and New England and on the continental shelf in these areas would also be subject to predation by pilot whales. If pilot whale stocks in these areas are not estimated in the foregoing assessment then short-finned squid consumption by pilot whales for the entire Northwest Atlantic could be much higher than figures tabulated for the stock investigated here.

Figures in this paper are estimates for only one predator and do not include consumption by other odontocetes or fish predators such as the Bluefin Tuna (*Thunnus thynnus*) which also feeds heavily on short-finned squid (Butler, 1971). It thus appears that annual production of the short-finned squid in the Northwest Atlantic can be conservatively estimated as at least several hundred thousand tons. Because of the short life-span the maximum sustainable yield can be a high proportion of the standing stock.

Conclusions

The distributions and migrations of the northern pilot whale and the short-finned squid show similar patterns and the former feeds heavily on the latter. Availability of pilot whales to the shore-based whaling operation at Newfoundland was closely correlated with the widely fluctuating abundance of squid inshore. Intensive hunting, particularly in the period 1951 to 1961, has severely depleted the pilot whale stocks and released a large surplus production of squid to other predators, including fisheries. In contrast to the over-exploited status of the pilot whale the large squid resource has remained virtually untapped by past and present fisheries.

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Table 1. Correlation coefficients and significance probabilities relating pilot whale catches to short-finned squid catches at Newfoundland, A - using total squid landings for Newfoundland, B - using squid landings for Conception Bay, Trinity Bay and Bonavista Bay.

Period	r	df	t	Prob. 1-sided	Prob. 2-sided
A					
1952-1956	.6778	3	1.5967	.10 < P < .15	.20 < P < .30
1957-1964	.4262	6	1.1540	.10 < P < .15	.20 < P < .30
1952-1964	.5145	11	1.9900	.025 < P < .05	.05 < P < .10
1952-1972	.5448	19	2.8319	.005 < P < .01	.01 < P < .02
B					
1955-1964	.5307	8	1.7710	.05 < P < .10	.10 < P < .20
1955-1968	.4194	12	1.6004	.05 < P < .10	.10 < P < .20

Table 2. Population estimates for Northern Pilot Whale stocks fished at Newfoundland as computed from models derived in the text. Raw data are given in the Appendix.

Model	Area	Period	Slope	Intercept	r	t	P 1-sided	N_0	N_{1947}
I	All Nfld	1952-1964	-0.0053	507.1801	-0.2618	-0.8997	.15 < P < .20	95,694	99,183
		1952-1967	-0.0075	539.0394	-0.4044	-1.6544	.05 < P < .10	71,872	75,361
	E. Nfld.	1955-1964	-0.0141	1046.5092	-0.2694	-0.7912	.20 < P < .25	74,221	86,747
		1955-1967	-0.0216	1160.9316	-0.4474	-1.6592	.05 < P < .10	53,747	66,273
II	All Nfld	1952-1964	-0.0106	6.2683	-0.4859	-1.8438	.025 < P < .05	49,772	53,261
		1952-1967	-0.0129	6.3783	-0.6937	-3.6037	.0005 < P < .005	45,653	49,142
	E. Nfld.	1955-1964	-0.0255	6.9830	-0.4661	-1.4901	.05 < P < .10	42,280	54,806
		1955-1967	-0.0289	7.0710	-0.7157	-3.3987	.0005 < P < .005	40,738	53,264
III	All Nfld	1952-1964	0.9280	5479.8803	0.9837	18.1457	<< .0005	76,103	79,592
		1952-1967	0.9031	6219.1899	0.9888	24.7976	<< .0005	64,182	67,671
		1952-1972	0.8997	5920.3758	0.9900	30.5833	<< .0005	59,027	62,516

Table 3. Possible consumption rates of short-finned squid (metric tons) by northern pilot whale stocks fished at Newfoundland for various levels of whale population size and consumption rates and assuming a one-species diet for the specified periods.

Feeding rate / Period No. whales	4%/day		6%/day	
	100 days	1 yr	100 days	1 yr
50,000	166,000	605,900	249,000	908,850
60,000	199,200	727,080	298,800	1,090,620
70,000	232,400	848,260	348,600	1,272,390
80,000	265,600	969,440	398,400	1,454,160

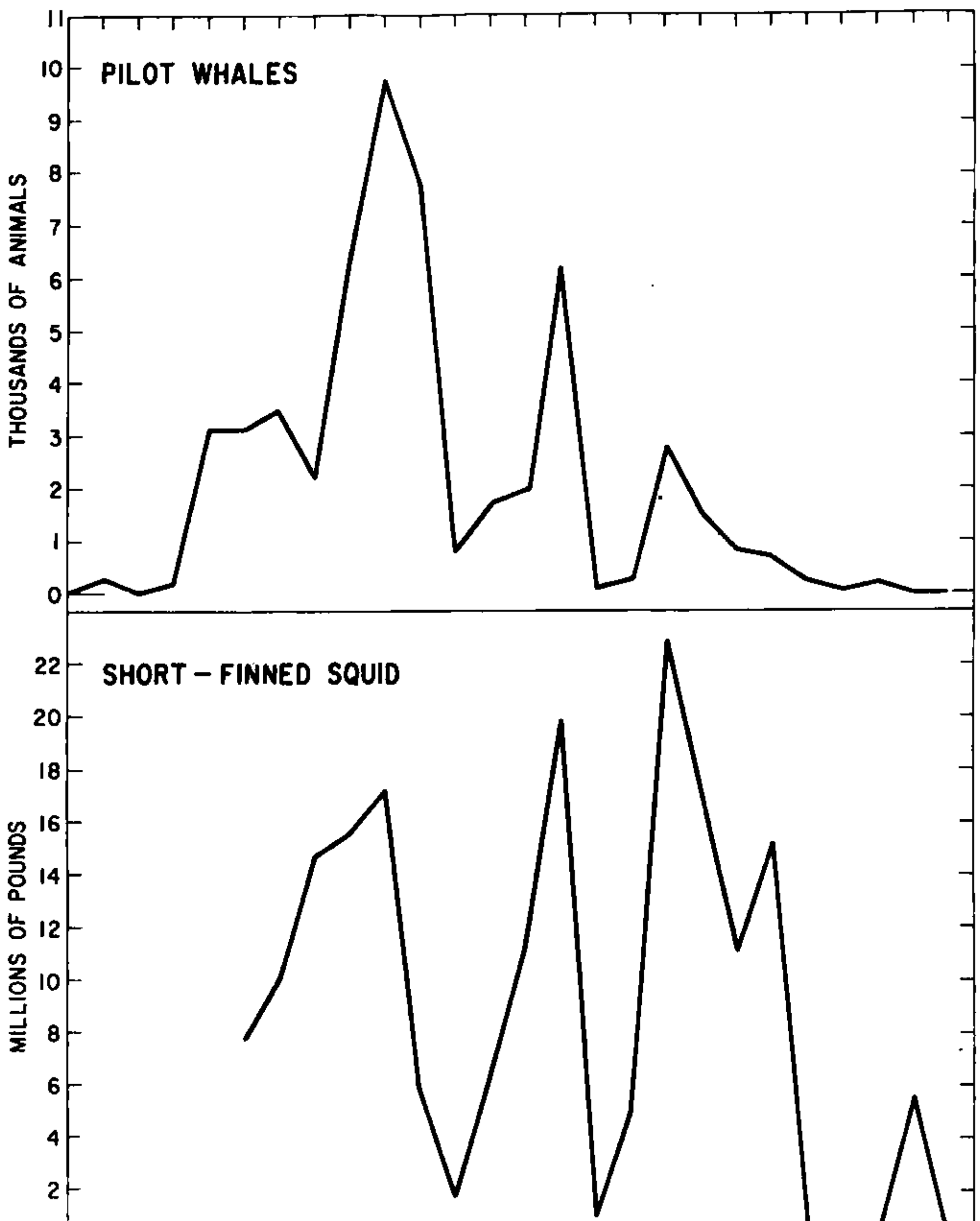

Fig. 1. Newfoundland landings of the Short-finned Squid and the Northern Pilot Whale.

Appendix

Landings data utilized in this paper. E. Nfld. refers to Conception Bay, Trinity Bay and Bonavista Bay

Year	Pilot whales (No.)	Nfld. squid (10^6 lb)	E. Nfld. squid (10^6 lb)
1947	0		
1948	215		
1949	0		
1950	172		
1951	3102		
1952	3155	7.6	
1953	3584	10.0	
1954	2298	14.7	
1955	6612	15.5	9.1
1956	9794	17.2	13.2
1957	7831	5.8	3.7
1958	789	1.6	1.1
1959	1725	6.3	4.3
1960	1957	11.2	7.9
1961	6262	19.8	12.9
1962	150	1.1	.1
1963	221	5.0	3.2
1964	2849	22.9	17.0
1965	1520	17.2	12.7
1966	887	11.1	6.7
1967	739	15.2	12.1
1968	204	.002	0
1969	123	.048	
1970	155	.2	
1971	4	5.5	
1972	0	.045	
1973	0	1.4	