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THE EFFECT OF FISHING ON SIZE COMPOSITION AND SEX RATIO OF OFFSHORE LOBSTER STOCKS

By

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INTRODUCTION

The initial effects of exploitation on marine stocks seldom have been thoroughly documented, because the stocks usually are not studied until a species has experienced a history of exploitation. The fishery for lobsters, *Homarus americanus*, in offshore waters of southern New England offers an opportunity to record the chronological changes due to exploitation. The fishery is in the early stages of development and fishing effort is expended disproportionately on relatively discrete grounds.

In this preliminary account of the data collected from the offshore fishery, I compare the size distribution and sex ratio of lobsters from several fishing grounds, and hypothesize that the differences are due mainly to fishing. The hypothesis was developed on the basis of work on sex ratio of lobsters by THOMAS (1955) and from data on size distribution collected from research cruises. Data are not yet available, however, on such aspects as seasonal migrations and total catch and effort by area, which must be considered if the effects of fishing are to be fully assessed.

THE OFFSHORE LOBSTER FISHERY

The history of the fishery for offshore lobsters has been reconstructed by SCHROEDER (1959). Lobsters were taken incidentally in the bottom trawl fishery for various species of groundfish in the early 1900's. In ensuing years, effort was expended specifically for lobsters, but catches through 1946 were less than 50 metric tons. SKUD (in press) described the recent increase in landings, which surpassed 500 metric tons in 1955

Contribution given in honour of Gunnar Rollefsen at his 70th birthday.

and 2500 metric tons in 1965. Fishing is conducted with a standard bottom trawl to the edge of the continental shelf, 100 to 400 km offshore, and is concentrated at depths between 100 and 500 meters. The use of the bottom trawl and the depth of fishing are in sharp contrast to coastal fisheries where lobsters are captured in pots, usually at depths less than 50 meters.

The offshore fishery is concentrated near submarine canyons at the edge of the continental shelf (Fig. 1). Five of these canyons have been sampled more intensively than others and can be grouped into three categories by distance from major ports of landing. Hudson and Veatch Canyons are 200 to 250 km offshore, Oceanographer and Lydonia between 250 and 300 km, and Corsair Canyon is about 400 km from the nearest port. Though historical catch records were not tallied by canyon, the canyons closest to shore generally have been fished more heavily than more distant canyons during the development of the fishery. In my analysis, I occasionally combined data from canyons that were equidistant from shore and that had lobsters of simliar size.

Samples were drawn from commercial landings; interviews with vessel captains provided information on the vessel, gear, area and depth of fishing, days fished, and total catch in pounds. At least 100 lobsters were measured and sexed in each sample. (Unless otherwise noted, all measurements refer to carapace length.) Data from research cruises included hydrographic data, time, distance, and the range in depth of each trawl tow. Sampling was concentrated in areas regularly fished by the commercial fleet. Each lobster was sexed, measured, and weighed, and the number of berried (egg-bearing) females was recorded. Research cruises provided information on prerecruits which was not available from commercial landings. Though the fishery operates in international waters, state laws apply to the landings; offshore catches are therefore subject to minimum size (approximately 8 cm) regulations that control the inshore lobster fishery.

CATCH PER UNIT OF EFFORT

To test the generalization that more distant canyons were less intensively fished, catch and effort of commercial vessels were compared by canyon. Effort was measured in days fished—length of the total trip, less fishing days lost. A vessel may fish at several canyons during a single trip but only those trips during which effort was concentrated in the vicinity of one canyon were compared. Further, the comparison was limited to vessels which had fished on at least two occasions in both areas being compared.

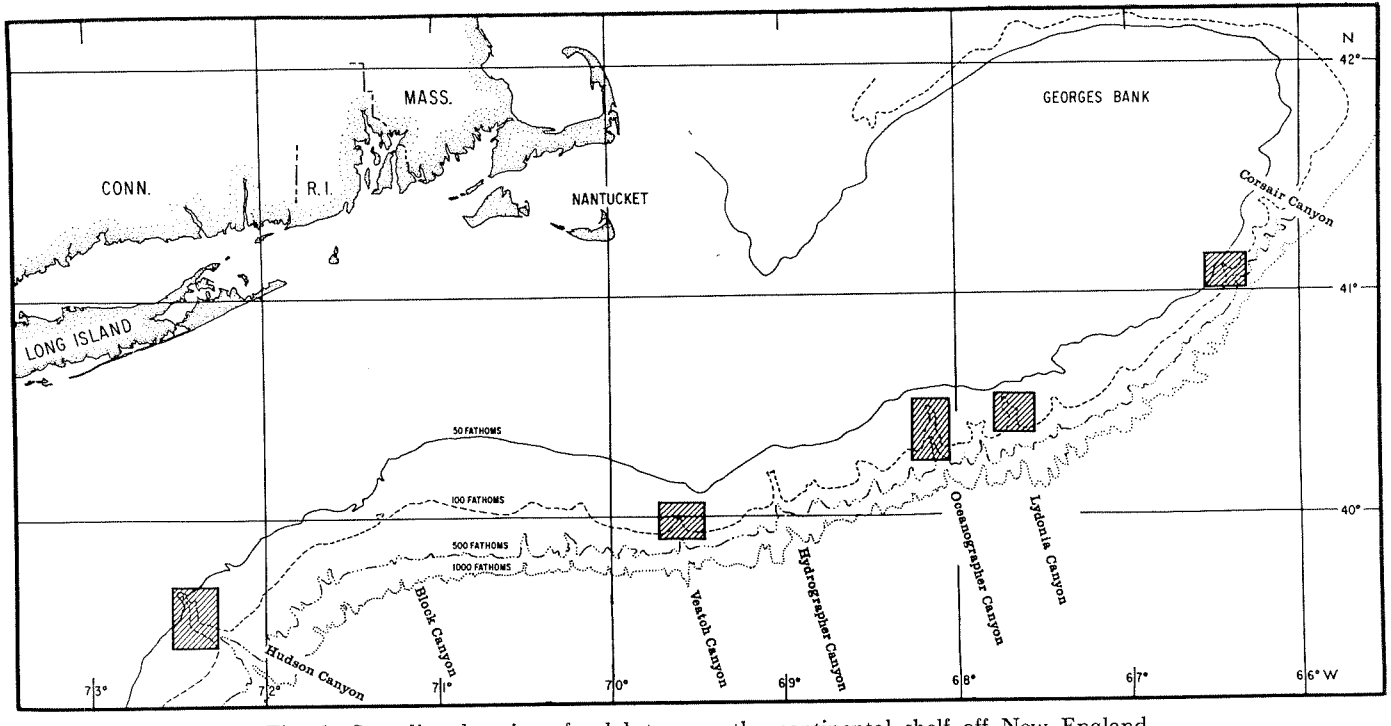

Fig. 1. Sampling locations for lobsters on the continental shelf off New England.

These criteria restricted the selection to six vessels, but included 63 interviews or trips. The average catch per day or catch per unit of effort (CPE) for each trip was determined for each vessel (Table 1). The mean CPE for the vessels ranged from 451 to 621 kg (average, 552) in the Hudson–Veatch area, from 539 to 706 kg (average, 670) in the Oceanographer–Lydonia area, and from 680 to 801 kg (average, 741) in Corsair

Table 1. Average daily catch (kilograms) of lobsters by six vessels in the offshore canyons, 1965–1967. [Entries in the table are the averages for each fishing trip.]

Canyon area	Vessel						A–F
	A	B	C	D	E	F	
Hudson-Veatch	363	665	389	794	486	499	
	605	806	455	303	616	403	
	377	340	713	907	489	—	
	455	340	766	831	756	—	
	562	737	—	495	583	—	
	357	455	—	395	455	—	
	499	377	—	—	455	—	
	801	—	—	—	368	—	
	1264	—	—	—	544	—	
	314	—	—	—	523	—	
	—	—	—	—	455	—	
	—	—	—	—	455	—	
	—	—	—	—	756	—	
Mean CPE	560	531	581	621	534	451	552
Number of trips	(10)	(7)	(4)	(6)	(13)	(2)	(42)
Number of days fished	(77)	(30)	(17)	(19)	(85)	(9)	(237)
Oceanographer-Lydonia	—	826	495	—	529	777	
	—	624	583	—	480	1021	
	—	484	—	—	907	777	
	—	—	—	—	624	907	
	—	—	—	—	990	428	
	—	—	—	—	—	837	
	—	—	—	—	—	408	
	—	—	—	—	—	324	
	—	—	—	—	—	706	
Mean CPE		645	539		706	687	670
Number of trips		(3)	(2)		(5)	(9)	(19)
Number of days fished		(17)	(18)		(36)	(62)	(133)
Corsair	—	—	—	—	—	680	
	—	—	—	—	—	801	
Mean CPE						741	741
Number of trips						(2)	(2)
Number of days fished						(16)	(16)

Canyon (only two trips, 16 fishing days, available for comparison). CPE at Hudson–Veatch, the area closest to the coast, was lower than at more distant canyons.

Assuming that the population densities at the canyons were comparable prior to exploitation, this trend in CPE indicates a more intensive exploitation at the canyons closest to shore. Though early records of total catch and effort are not available to establish this premise, the statistics now being collected and subsequent changes in CPE may help determine the distribution of past fishing effort. The size composition data in the following section do lend support to this thesis.

SIZE COMPOSITION

The mean size of lobsters was related to the distance from shore. Length-frequencies of lobsters were smallest at Hudson and Veatch Canyons, intermediate at Oceanographer and Lydonia Canyons, and largest at Corsair Canyon (Fig. 2). This trend in size follows the expected diminution from fishing, i.e., Hudson and Veatch Canyons lie closest to the coast and presumably have been more intensively fished. CPE was lowest at the Hudson–Veatch area, higher in Oceanographer–Lydonia, and highest at Corsair Canyon.

The data from Veatch Canyon are more extensive than those from the other canyons, and show marked changes in size composition during the three years of sampling. The cumulative percentage of catch of

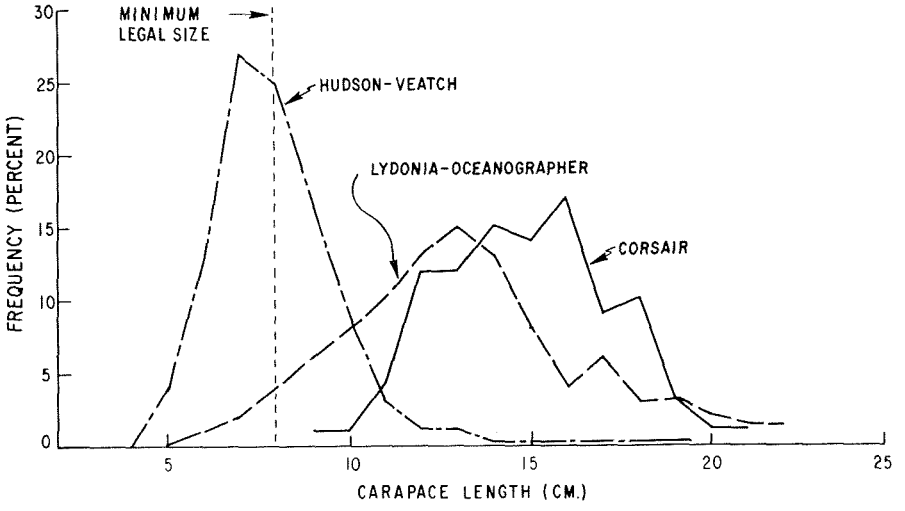

Fig. 2. Length-frequencies of lobsters in catches by research vessels at offshore canyons, 1965–67.

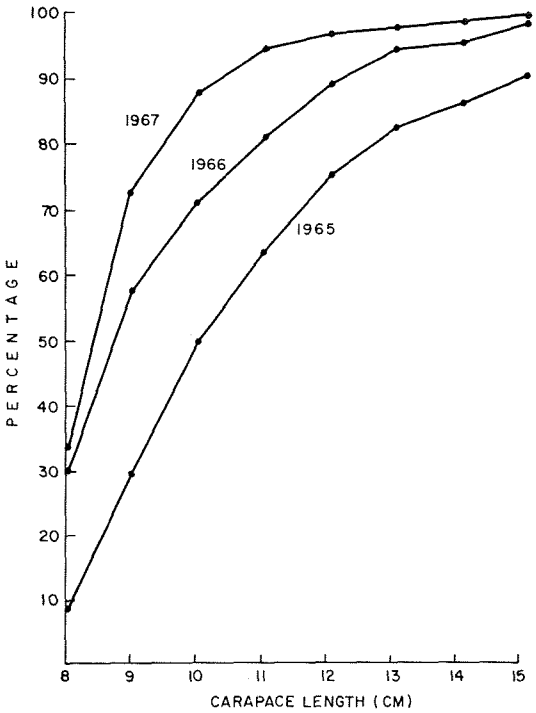

Fig. 3. Cumulative percentage of the catch of legal-sized lobsters at Veatch Canyon, 1965–67.

lobsters 8 cm and larger showed that smaller lobsters accounted for progressively more of the catch (Fig. 3). For example, the percentage of lobsters in the 8 to 10 cm size group was 50 in 1965, 70 in 1966, and nearly 90 per cent in 1967. This progressive change is assumed to be caused by fishing.

Additional evidence that differences in size distribution are related to fishing was obtained by comparing the present data with that reported by McRae (1960) from exploratory cruises made 10 years ago. The modal size of lobsters from Veatch and Lydonia Canyons was smaller in 1965–67 than in 1956 and the decrease in size was greatest in Veatch Canyon which is closest to shore (Fig. 4). The depth of water in which samples were taken ranged from 200 to 500 meters in 1956, however, and from 100 to 300 meters in 1965–67. Since the size of lobsters generally increases with depth, the differences in depth fished in the two periods have contributed to the apparent change in size distribution (Skud and Perkins, in press). To examine this relationship of size with depth, data from recent research cruises have been grouped by depth for comparison (Table 2).

The maximum increase in size with depth was 1.1 cm, whereas the difference in size between canyons was as much as 6.7 cm. Thus a

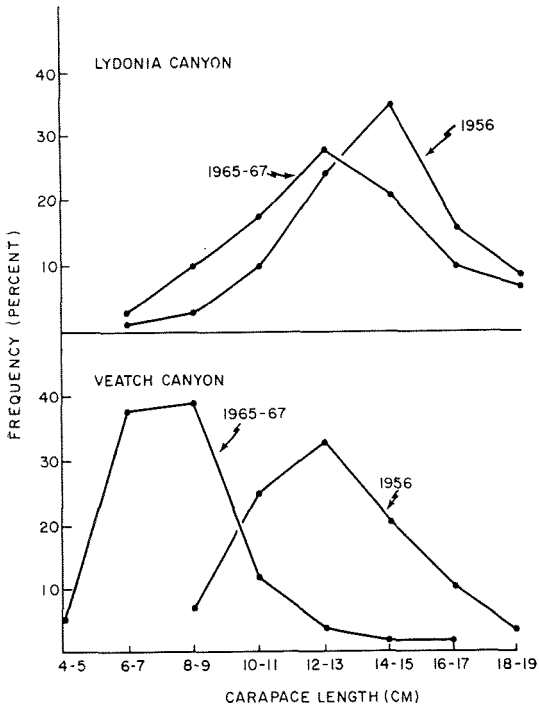

Fig. 4. Comparison of length-frequencies of lobsters collected in 1956 and in 1965—67 at Veatch and Lydonia Canyons.

Table 2. Average carapace length of lobsters by depth of capture.

Canyon	100–200 meters Mean size (cm)	200–300 meters Mean size (cm)
Hudson–Veatch	8.0	8.7
Oceanographer–Lydonia	11.9	13.0
Corsair	14.7	15.4

factor other than depth accounted for most of the difference between the size distribution of the lobsters in 1956 and 1965–67.

TEMPLEMAN (1936) and others have correlated size of lobsters with temperature and undoubtedly the growth in offshore stocks can be similarly affected. However, it seems unlikely that temperature differences could account for the magnitude and the progressive nature of the changes in size recorded at the canyons.

SEX RATIO

THOMAS (1955) constructed a model of a lobster population with a uniform mortality rate, and showed the expected change in sex ratio with size (Fig. 5). The model assumed that mature females molted

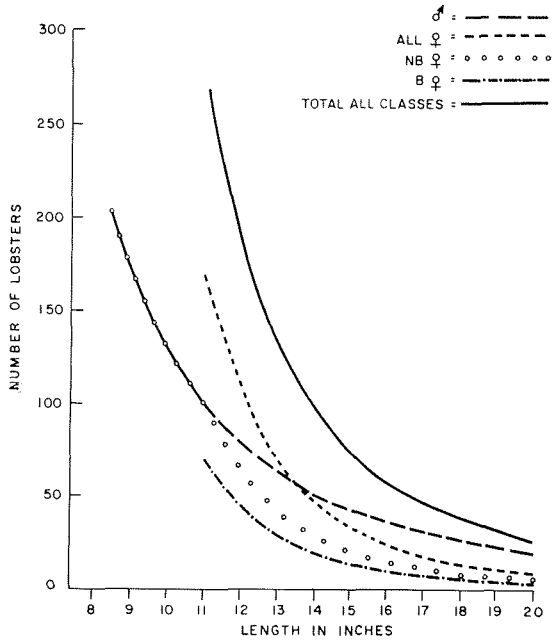

Fig. 5. Size comparison in a model stock, based on a uniform recruitment of 100 males and 100 females at a maturity size of 11 inches (total length) and a 30% total mortality rate. B = berried; NB = Non-berried. (After THOMAS 1955).

only once in 2 years, whereas males molted every year. Biennial molting by females was reported by GARMAN (1892) and later supported by HERRICK (1896) and others. Exceptions do occur but WILDER's (1953) data showed clearly that the proportion of non-molting females increases with size at or near maturity. He also showed that males do not always molt annually. Nor is the molting cycle consistent in the offshore populations, particularly in the largest individuals (15 cm or more) that may molt but once in 3 years. However, I do not consider these exceptions as a serious defect of the model, for regardless of the source, the data indicate that, collectively, males molt more frequently than females.

In the model, the sex ratio of immature lobsters is assumed to be 1 : 1. After maturity, the less frequent molting of females causes them to outnumber males at any given size. For example, mature females at 8 cm would remain in this size category and be joined by previously immature females that had molted, whereas males at 8 cm would have molted and progressed to the next size group. If no mortality occurred for either sex, and if all females matured at precisely 8 cm, the ratio of females to males would double at that size. In actuality, all females do not mature at the same size and, as natural and fishing mortality reduce the numbers, the proportion of females increases gradually and the sex ratio can never be expected to reach 2 : 1 (Fig. 6).

Growth rate also influences the observed changes in sex ratio. In

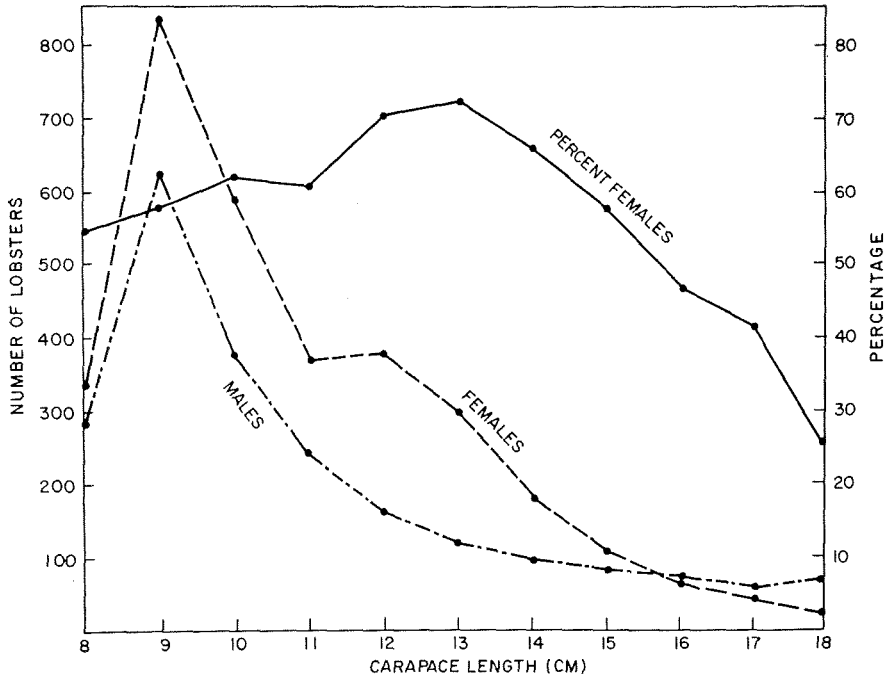

Fig. 6. Numbers of males and females and percentage of females in commercial samples from Veatch Canyon, 1965—67.

the model, the growth increment per molt was considered to be 14 percent. For the offshore lobsters, preliminary estimates showed that growth between molts was 15 percent for mature females, whereas, the increment for mature males was 18 percent. TEMPLEMAN (1936) also observed differences in growth between the sexes after maturity. This difference concentrates the number of females in smaller length classes and the slower growth, coupled with the less frequent molting, results in an increase in the proportion of females at given sizes.

The increased number of females over males with size is apparent in offshore lobster stocks and can be followed over a greater size range than in coastal stocks (Fig. 6). The increase in the proportion of females with increasing size does not continue indefinitely, but the decline in the rate of increase depends on the rate of mortality. THOMAS (1955) concluded that the change in sex ratio could be used to estimate mortality and showed the expected differences in sex ratio in two models, one with a total annual mortality of 70 percent and another with a 30 percent mortality. When annual intermolt mortality of males is 70 percent, mortality between biannual molts of mature females is 91 percent. Or,

if mortality is 30 percent for males, the intermolt mortality of females is 51 percent.

In offshore lobster stocks the proportion of females continues to increase until 12 or 13 cm. In the model the proportion of females was highest at a size class 2 or 3 cm smaller than in the offshore stocks; the difference suggests that offshore lobsters mature at larger sizes than that assumed in the model. However, it is possible to compare the decline in the percentage of females (larger than 13 cm) in the offshore stocks with the changes of sex ratio in the model. The rate of decline at Veatch Canyon most closely approximates that of a 50-percent annual mortality, whereas that from Oceanographer and Lydonia conforms most closely to a 30-percent mortality; these rates suggest a 20-percent greater fishing mortality at Veatch Canyon, if the natural mortality in the two areas is equal (Figs. 6 and 7).

RECRUITMENT

COLE (1954) provided an excellent summary of "population consequences" expected from changes in birth rates and death rates. Under exploitation, he listed three expected changes: (1) a decrease in longevity; (2) an increase in the population's birth rate; and (3) the obvious in-

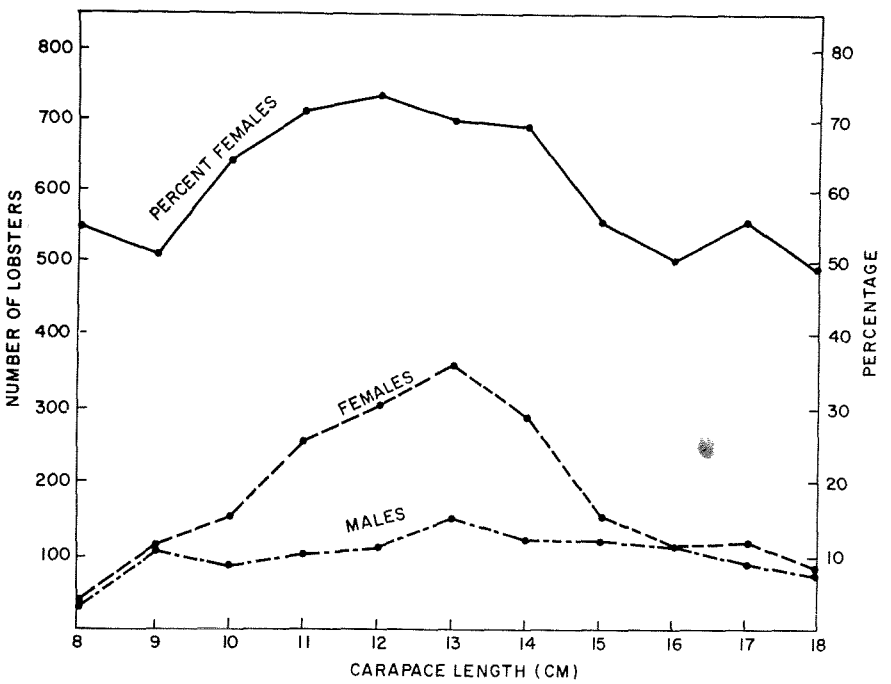

Fig. 7. Numbers of males and females and percentage of females in commercial samples from Oceanographer and Lydonia Canyons, 1965–67.

crease in the proportion of young. Items 1 and 3 are demonstrated clearly in the length-frequencies of lobsters presented earlier, and also from the data on catch per unit of effort (CPE). The average weight of legal-sized lobsters from Hudson and Veatch Canyons approached 1 kg; conversion of the mean CPE (552 kg) from weight to numbers indicated a catch of over 500 lobsters per day. At Oceanographer and Lydonia Canyons, where the average weight was about 2 kg, the converted CPE (670 kg) was 335 lobsters per day. Lobsters at Corsair Canyon averaged 2.7 kg and the converted CPE (741 kg) was 257 lobsters per day.

Item 2, an increase in the birth rate, is difficult to measure in the offshore fishery. Increased birth rate in a population may be reflected in changes of the age or size at first maturity. For lobsters, such a change can be measured by comparing the number of egg-bearing (berried) females to the total number of females at a given size. I have tallied the percentage of berried females taken during the research cruises in 1956 (from McRae 1960) and 1965–67 (Table 3). In 1956, no females were berried at 8 or 9 cm and less than 20 percent were berried at 10 and 11 cm. In 1965–67, a few females were berried at 8 cm, over 20 percent at 9 cm, and more than 30 percent at 10 and 11 cm. This change, which could be due to an increased growth rate, may indicate an increased birth

Table 3. Percentage of berried lobsters among females of different size groups collected in canyons off New England during exploratory cruises in 1956 and research cruises in 1965–67.

Length (cm)	1956		1965–67	
	All females (Number)	Berried females (Percent)	All females (Number)	Berried females (Percent)
6	0	0.0	363	0.0
7	2	0.0	464	0.0
8	12	0.0	441	1.6
9	31	0.0	343	22.7
10	45	11.1	232	33.2
11	122	18.9	133	30.8
12	98	25.5	168	25.6
13	191	35.1	163	27.0
14	131	35.1	121	30.6
15	225	31.1	94	29.8
16	134	26.9	64	37.5
17	52	32.7	46	19.6
18	36	38.9	40	40.0
19	11	45.5	16	18.8
20	3	33.3	3	66.7

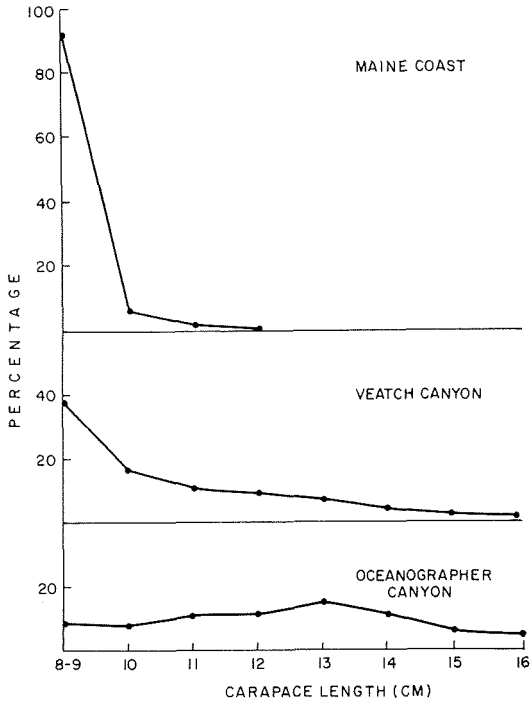

Fig. 8. Size composition of lobsters from inshore and offshore areas (both sexes).

rate and suggests that the increasing proportion of small lobsters in the offshore catches is not only the result of cropping the larger individuals. However, additional information is necessary to determine whether total egg production has increased or whether the improved recruitment of immatures and young adults has been influenced by other factors such as emigration.

COMPARISON WITH THE COASTAL POT-FISHERY

The inshore lobster fishery in Maine is very intense; at the peak of the fishing season more than 4,000 fishermen (including 2,000 part-time) fish more than 750,000 lobster pots. Dow (1964) estimated that recruit lobsters (8 to 9 cm) accounted for 80 to 90 percent of the Maine landings (Fig. 8). The size distribution in the coastal waters is in sharp contrast to that of lobsters offshore, even in the most intensively fished areas. In canyon areas that are fished less intensively, recruits account for only 5 percent of the catch and the dominant size group at some canyons is 13 cm or more.

The proportion of females in the inshore fishery is seldom more than 51 or 52 percent. I examined the sex and size data from 2,500 lobsters

collected along the Maine coast.[1] In the size class from 8 to 10 cm, the proportion of females was 49.8 percent, whereas in the 11 to 12-cm size group only 45.1 percent were females. Male and female lobsters of over 11 cm accounted for only 4 percent of the sample.

The relatively low proportion of females at sizes from 8 to 12 cm and the small contribution of lobsters over 11 cm in the inshore sample are consistent with a total mortality of 90 percent in THOMAS' (1955) model and confirms DOW's (1964) estimate. The model shows an expected 52 percent females in the 10-cm size class, and shows that only 5 percent of the population remains at the next molt (approximately the 11-cm size class). The proportion of females at 11 cm is higher in the Maine sample than the model predicts, but this proportion may be influenced by the release of berried females that are protected by law.

Exploitation of the Maine fishery is apparently so high that there is little or no increase in the proportion of females. TEMPLEMAN'S (1936) data from the coastal fishery at Seal Island, Nova Scotia does show a moderate increase in the proportion of female lobsters between the 7 to 10 cm length classes. The proportion of females increased to 58 percent at 10 cm and then declined. The sample excluded berried lobsters, which suggests that the increase was greater than indicated; and this exclusion precludes any detailed comparison with the model. However, the changing sex ratio with size does conform and the proportion of females at 10 cm would indicate a fishing intensity less than that in Maine but greater than that offshore.

SUMMARY

The lobster fishery in the offshore waters of southern New England is in the early stages of development. The assumption that canyon fishing grounds closest to shore are the most heavily fished was supported by a lower catch per day (CPE), a smaller mean size, and a higher total mortality than exists in more distant canyons.

At Hudson and Veatch Canyons, less than 250 km offshore, the average CPE was 552 kg; Oceanographer and Lydonia Canyons extend 300 km offshore and had a CPE of 670 kg; and at Corsair Canyon, which is 400 km from shore, CPE was 741 kg. Lobsters were smallest at the canyons which were closest to shore and had the lowest CPE. The size frequency was higher at the canyons of intermediate distance and the CPE was higher. The largest lobsters were from Corsair Canyon, which is the furthest from shore, and had the highest CPE.

The modal carapace length of lobsters at Veatch Canyon was over 12 cm in 1956 and is now less than 9 cm. In three successive years of

[1] Data provided by JAMES THOMAS, Maine Department of Sea and Shore Fisheries.

sampling (1965–67), the contribution of small lobsters has increased and in 1967 more than 90 percent of the legal-sized lobsters were from the 8 to 10 cm length class. The progressive change at Veatch Canyon and magnitude of size differences among canyons are greater than expected from the influence of temperature or depth of fishing.

Observed changes in sex ratio support the basic assumptions made in THOMAS' (1955) model and follow the expected changes at different levels of mortality. The proportion of females to males increases gradually from 8 cm to 13 cm and then declines. Because females molt less frequently than males, their numbers at a given size decline more rapidly. The model assumes that females molt only every two years; whereas, males molt annually and have a lower intermolt mortality. The change in sex ratio was used to estimate mortality in the offshore fishing grounds. The more distant canyons had a lower mortality, higher catch per unit of effort, and larger size composition. The size composition and sex ratio of coastal lobster fisheries indicated that exploitation was more intense than in offshore fisheries.

The increased proportion of young lobsters in the offshore catches followed expected changes from exploitation, but also suggested an increase in the population birth rate. This possibility was supported by the observation that in ten years the percentage of berried females at smaller sizes of maturity had increased substantially. However, additional data are needed to determine whether the improved recruitment has resulted from other factors.

Additional data and analyses are needed to test the hypothesis that fishing has caused the changes in size composition, sex ratio, and catch rates. If the assumptions hold and the level of fishing continues or increases, the more distant canyons are expected to experience changes in lobster size, sex ratio, and catch rates—comparable to those at the canyons closest to shore.

The size at maturity, frequency of molting, and rate of growth used in the model are not entirely consistent with observations in the offshore fishery. However, the basic concepts seem applicable and the necessary adjustments and corrections can be incorporated into the model when sufficient data are available.

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