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Bioeconomic Relationships for the Maine Lobster Fishery with Consideration of Alternative Management Schemes

ROBERT L. DOW, FREDERICK W. BELL, and
DONALD M. HARRIMAN

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Bioeconomic Relationships for the Maine American Lobster Fishery with Consideration of Alternative Management Schemes

ROBERT L. DOW, FREDERICK W. BELL, and DONALD M. HARRIMAN[1]

I. INTRODUCTION

The American lobster *(Homarus americanus)* was an important food source to the indigenous coastal peoples and later to the early European settlers. Until the early decades of the 19th century, however, the Maine lobster resource was not fished commercially to any appreciable extent. Out-of-state lobstermen first appeared off the Maine coast in Casco Bay during 1826. This development marked the beginning of the commercial fishery and was a direct result of the growing demand for lobsters in the New York City and Boston markets. Resident and nonresident fishermen participated, extending their operations eastward to Penobscot Bay and Eastport by 1850. Shipbuilding and sailing were the major occupations of the Maine coastal population; lobstering was a seasonal, part-time vocation.

Lobster pots evolved as the most important type of gear during the early stages of the fishery, replacing hoop nets, gaffs, dip nets, and hook and line. Live lobsters were transported to urban markets aboard wet-well smacks equipped with holds in which seawater circulated freely. Dry-well smacks, similar to ordinary cargo carriers, were also used. During its earliest stages, lobster fishing was limited to those areas served by public transportation.

As the demand for American lobster expanded over the last hundred years, it was quite apparent that the once virgin lobster stock was increasingly exploited. The increasing depletion of fishing grounds in several areas off the coasts of the United States has created many problems of biological as well as economic nature.

Unlike most industries, the inshore lobster industry is faced with the problem created by a common property resource. The nature of this resource produces many unique problems and has given rise to many "conservation" objectives. Because unlimited entry to a common property resource produces excess capacity, it is the purpose of this report to present a theoretical and empirical basis for the "conservation" of capital and labor in exploiting inshore American lobster resources. We shall define "conservation" in a broad sense to include the efficient and economic use of capital, labor, and the American lobster resource.

Biologists embark on studies concerning the rehabilitation of these fishing grounds, their maintenance, and eventually the accomplishment of higher yields. Economists follow closely the loss of income which occurs in connection with depleted areas, the increased flow of income in connection with rehabilitated areas, and the effects of price changes on production and vice versa.

Most of the studies undertaken until now were either done by biologists alone or by economists alone. Independent studies by each group, separate from the other group, and independent solutions to specific problems may lead to unsound conclusions both from a biological and an economic viewpoint.

Because of these conditions and the interaction of economic and biological forces, a combined study of the management problem in the biological field and of problems with respect to price and marketing would appear to yield fruitful results as to principles involved in this interacting process.

The objectives of this study shall be as follows:

(1) To measure the biological factors that determine the trend and fluctuations in abundance and production of the Maine American lobster;

(2) To analyze the impact of such economic forces as the demand for lobster and cost of operations on the production of lobster from this biological resource;

(3) To measure the returns to lobster boat owners operating in the fishery;

(4) To establish a model for evaluating the economic-biological interrelationships so important to fisheries management;

(5) To analyze the impact on fishermen and the lobster resource of alternative management schemes designed to prevent excessive capitalization of the fishery;

(6) To determine if the economy and fishing industry will be improved by better fishery management.

[1]The late Donald M. Harriman contributed extensively to the biological portion of the study. Robert L. Dow is Research Director of the Department of Marine Resources (Maine) (formerly the Department of Sea and Shore Fisheries), while Frederick W. Bell is currently Professor of Economics at Florida State University. We would like to thank Terry Ellington and Richard Kinoshita for their help in some of the statistical analyses and Shelva Page for her editorial and typing assistance.

II. BIOLOGY OF AMERICAN LOBSTERS

A. Range and Distribution.

The American lobster occurs in varying density of population from the Strait of Belle Isle (Labrador-Newfoundland) in the north to the offshore waters of the Carolinas in the south. Its range extends seaward in several areas to the Continental Slope. The three major commercial concentrations are along the Maine and the Nova Scotian coasts and in the Gulf of St. Lawrence (Fig. 1). A population which is being fished with increasing intensity occupies the outer shelf and slope of the Gulf of Maine and the offshore grounds to the south.

The most productive trapping areas are those in the vicinity of ledge outcrops, glacial drifts, and talus slopes. Traps set near ledges or boulders catch more lobsters than traps on smooth and unbroken bottom. Since lobsters appear to be primarily trapable when they are hunting for food (frequently they may seek shelter in a trap) the location of traps near burrows or other hiding places permits capture of lobsters with a minimum of effort by fishermen.

B. Environment.

Lobsters apparently will occupy any type of sediment—sand, clay, or silt—provided cover debris is available for shelter. The greater the concentration of hiding places the greater appears to be the concentration of population. Except when they are foraging, lobsters occupy hiding places under rocks, boulders, or other bottom debris, crevices in underwater ledges, or voids between submerged glacial boulders.

Lobsters are found on both smooth and rough bottom. The highest concentrations occur in rocky areas which serve as anchorage for plants and provide cover for many food organisms. Such systems are attractive to other predators, so lobster survival in them is a function of cover available. On smooth bottoms concentrations of food and predators are lower, and lobsters are more prone to move. Movements on smooth bottom do not appear to represent purposive migra-

Figure 1.—North American average lobster landings, 1956-60. (Figure courtesy of D. G. Wilder, Fisheries Research Board of Canada.)

tion, but may be influenced by temperature gradients to produce what may seem to be substantial seasonal movements of the population as a whole.

There is no reason to believe that separate subpopulations inhabit these three areas. Any lobster apparently adopts the appropriate behavior patterns to the environment in which it finds itself.

C. Food.

The important foods of lobsters are not well known. Lobsters are known to be scavengers, and will eat almost any dead flesh available. This characteristic is exploited by the fisherman who baits his trap with dead fish. Some biologists believe that the lobster may supplement such food with microscopic plants combed from the back or collected on the gills, and with seaweed growing on rocks. Lobsters dig, shuck, and eat soft shell clams and other shellfish. Bait and other lobsters in traps also contribute considerably to the food requirements of lobsters in intensively fished areas. Underwater observations have been made of lobsters retrieving bait from traps. It is estimated that approximately 18,000 to 22,000 metric tons of bait are used in Maine annually. Regardless of the major source of nutrition, the lobster is apparently able to exist for long periods without food. The metabolic rate is slow, and infrequent feeding is the rule. Death from lack of food is unusual except at moult. Shedding the shell is an exhausting process; a weak lobster often dies in the act.

Living on the ocean bottom, among and under rocks and in burrows, and seeking shelter of rockweeds, kelps, and other marine algae, the lobster is a relatively sedentary animal, foraging at night but generally quiescent during daylight. Observations under natural, seminatural, and laboratory conditions indicate that lobsters eat both living and dead fish, mollusks, other marine invertebrates, and small quantities of marine plants.

D. Migration.

The lobster in the northern part of its range is a sedentary animal and therefore nonmigratory wherever rocky bottom or ledge outcrop provides shelter and where food is available.[2] At times, because of lack of shelter, shortage of food, or for unknown reasons, lobsters will be found over considerable areas of smooth mud or sand bottom. Unlike lobsters in a rocky environment, these animals seem to be constantly moving. The movements are random, but some tagged individuals may wander many miles from the point of release. Lobsters tagged and released within the limits of restricted hydrographic features are frequently and repeatedly recaptured. Random and erratic movement of the straggler may reflect inability of the captured, tagged, and released lobster to find its burrow after inadvertent displacement. The numbers of such stragglers may also reflect population pressures on the available cover.

The movement of stragglers when it has occurred appears to be coastwise and not inshore or offshore. To what extent this movement has been assisted by man or the counterclockwise, nontidal drift in the Gulf of Maine is not known. When these wanderers find shelter, they burrow in and revert to the more characteristic pattern of extended periods of inactivity punctuated by foraging expeditions for food.

In Maine the popularly held belief that extensive inshore-offshore seasonal migrations occur appears to be related to the degree of activity associated with changes in seawater temperature. In the late fall and early winter as air temperature declines, the shallow inshore waters cool first. As these waters cool, lobsters inhabiting them become less active and ultimately cease to forage. Deeper water, farther from shore, is still warming so that lobsters living there continue in activity and are trapable.

As deeper and more seaward water becomes cooler, lobsters become progressively less active. During the coldest part of the winter lobsters are active only in the deepest and warmest water, which is generally the farthest from shore. In the spring and summer the cycle is reversed, with deep water at its minimum temperature, and creates the false impression that lobsters are migrating shoreward.

E. Life History.

(1) Egg and Larval Stages.—Shortly after moulting, while the new shell is soft, the mature female is inseminated by a hard-shelled male. Following approximately a year, the eggs are extruded from the ovaries and fertilized by the sperm which has been retained in the seminal receptacle. The fertilized eggs are attached in an adhesive mass to the swimmerets under the tail (Fig. 2). The number of eggs produced varies geometrically with the size of the female; a range from approximately 6,000 to 40,000 eggs has been reported from measurements at Boothbay Harbor for lobsters with a carapace length range from 82.5 to 127 mm (Taylor, 1950). During the warm months of the following year the eggs complete incubation and hatch.

The length of the free-swimming larval period varies largely with seawater temperature from a minimum 2 weeks at 20° to 21°C to a theoretical maximum of approximately 2 mo with low temperatures.

(2) Moulting.—At periodic intervals throughout life, varying with the rate of growth and commencing at the end of the first larval stage, the lobster moults. The interval of moulting varies with size, occurring several times each year in 1 and 2 yr old juveniles, and averaging approximately once each year among mature males and immature females of legal size. Maine

[2]Anonymous, 1957; Harriman, 1957; Wilder, 1957.

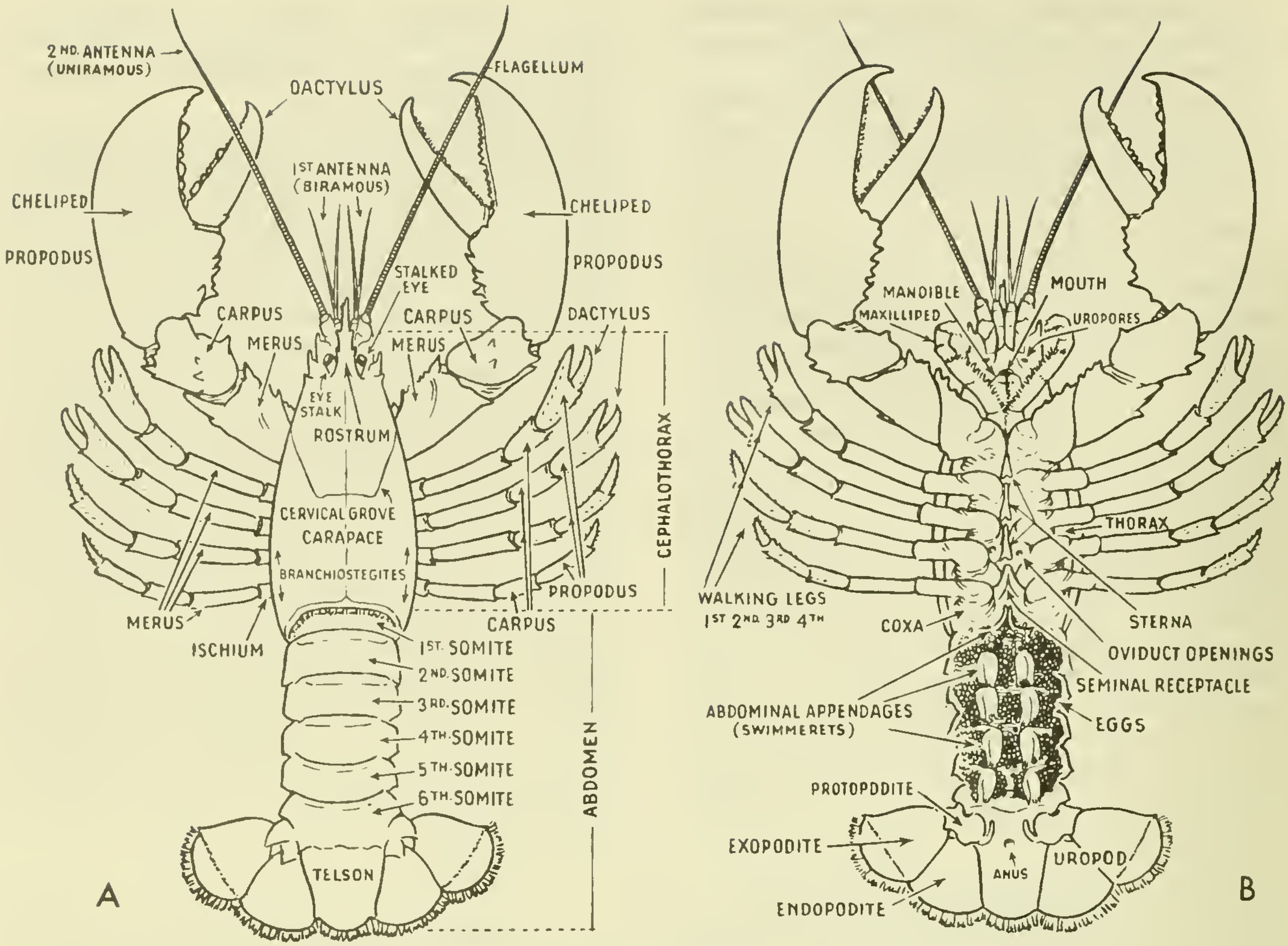


Figure 2.—Diagram of female lobster (A. Dorsal view. B. ventral view).

has had both a minimum and a maximum carapace legal size restriction since 1933. The minimum size was increased from 3¹/₁₆ in. (78.6 mm) to 3⅛ in. (79.4 mm) in 1942 and 3³/₁₆ in. (81.0 mm) in 1957. The maximum size was increased from 4¾ in. (120.7 mm) in 1933 to 5 in. (127 mm) in 1935 and to 5³/₁₆ in. (131.8 mm) in 1957. In 1960 the maximum size was reduced to 5 in. (127 mm) again. Frequency of moult of the population as a whole probably varies more with seawater temperature than with any other factor. By the time lobsters have reached approximately 127 mm carapace length, a significant percentage are moulting every other year, and very large lobsters may moult at 10- to 15-yr intervals.

While moulting frequency is largely differentiated by size, the frequency and time of moult for any given size is primarily influenced by water temperatues, particularly during the spring and early summer. Frequency is increased by high temperatures and reduced by low. Although individual lobsters may moult at any season, for the majority this debilitating experience takes place sometime between May and October when water temperatures are relatively high.

The lobster is a comparatively slow-growing animal and is believed to be long-lived. Moulting depends upon growth and growth depends greatly upon food intake. The frequency of feeding appears to be related to general activity, which is influenced by water temperatures. Post-moult feeding activity is high and is generally associated in Maine with seasonally high seawater temperatures. Those conditions concentrate the catch of lobsters in the 5-mo period, July to November, when about 75 percent of the annual catch is made.

Growth rates vary among individual lobsters. The frequency of moult varies and the actual growth increment made with each moult varies. From studies in Maine (Taylor and Baird, 1948; Taylor, 1949), it is likely that the most precocious lobsters in Maine waters reach minimum legal size (3¹/₁₆ in. or 78.6 mm) when they are 4 yr old. The number must be small and probably does not exceed 5 percent. The majority are believed to enter the fishery when they are 5 to 7 yr old, while another small percentage may be 9 yr of age or older before they reach minimum legal size.

(3) Length-Weight Data.—Sampling of the catch indicates in Table 1 the relation of total live weight to carapace length for selected carapace sizes.

Measurement of lobsters for length-weight distribution from 1949 to 1956 indicated that growth averaged about 14 percent in carapace length and 50 percent in weight with an average moulting frequency of approximately 12 mo or less. Actual gross samples with a total of 282,057 lobsters ranged in weight increase from 44.7 percent to 53.6 percent with an average for all samples of 49.4 percent (Table 2).

Table 1.—Length-weight relation of American lobsters.

Carapace length (*mm*)	Number of lobsters in sample	Average weight (*grams*)
79	54,130	407
83	50,500	457
86	46,442	511
89	38,585	567
92	16,210	625
95	5,959	694
98	3,994	766
102	2,975	844
105	2,368	921
108	1,438	1,005
111	1,076	1,094
114	802	1,192
117	569	1,291
121	427	1,396
124	295	1,505
127	86	1,578

Table 2.—Lobster weight increase by moult; gross samples.[1]

Moult	Percent increase
First	53.6
Second	51.9
Third	50.1
Fourth	48.8
Fifth	47.5
Sixth	44.7
Mean	49.4

[1]Gross sample weights derived from length frequency distribution measurements of 288,601 lobsters made from 1949 to 1957, show differences in weight by moult classes.

(4) Soft-Shell Lobsters.—As a result of increased meat tissue, the lobster's body becomes too large for its shell. This is the primary cause of moulting, although not necessarily the mechanism which determines the time of moulting. The process of moulting takes from 15 to 20 min. The new shell is soft and rubbery and does not provide the lobster with any protection from enemies. For a short time after moulting the lobster has to remain inactive.

By the time the shell has reached the latter half of the second intermoult stage described by Donahue (1954), the lobster is ready to forage and is easily trapped. Approximately 60 percent of the annual catch consists of soft-shell lobsters. In addition to having a thin soft shell, lobsters of this class have a comparatively low ratio of meat to shell and shell liquor. Commercial shucked meat ratio to live weight at this stage is approximately one to eight, whereas at the maximum yield (just before moulting) the ratio is approximately one to four. During this period meat yield is small and the problem of holding and shipping live lobsters to market is great.

The excellent summer demand for lobster by tourists absorbs a large part of the July-August shedder catch. Approximately 25 to 30 percent of the annual catch is marketed in the Northeast during this period to tourists. The catch in excess of this amount and that made during the early fall at the end of the tourist season is generally held in tidal pound storage for shell hardening and meat quantity and quality improvement for later marketing when the catch is low.

(5) Hard-Shell Lobsters.—Hard-shell lobsters are defined by the industry as those whose shells have developed and hardened so that they are quite resistant to digital compression. When the shell is firm the lobster is able to survive handling by the producer, the buyer, the dealer, and the retailer much better than can the soft-shell lobster. In addition to having a stronger shell, the hard-shell lobster has eaten sufficiently in most instances so that the percentage of meat tissue to live weight has increased. This increase in meat density will continue provided the lobster is able to feed regularly until he is ready to moult again. The hard-shell lobster commands a premium market price for obvious reasons. He is more viable and can better withstand the rigors of handling. Meat yield is greater—approximately 25 percent as compared with about 12.5 percent for soft-shell lobsters.

F. Growth and Mortality Rates.

Stratified sampling of the catch supports the assumption that the resource is intensively exploited (see discussion in III below).

Between 1939 and 1957 measurements were made of the catch to determine the size of individual lobsters and the number of lobsters in various carapace size classes. Table 3 shows the size of the sample in numbers and weight in relation to catch. During the period, 348,645 lobsters (weighing 182.5 metric tons) were measured by Fish and Wildlife biologists and Department of Sea and Shore Fisheries wardens and biologists.

Between 1949 and 1957 the Department of Sea and Shore Fisheries measured 286,244 lobsters weighing 150 tons, representing one-fifth of 1 percent of the catch during the 9-yr period, for the purpose of determining: (1) the size of individual lobsters, and (2) the number of lobsters in various size classes (Table 4). It was assumed that size distribution data would produce information on: (a) the approximate percentage of

Table 3.—Sampling of commercial lobster catch for size distribution.

Lobster year	Commercial catch (*metric tons*)	Sample (*metric tons*)	Commercial catch (*Number*)	Sample (*Number*)	Sample (*Percent*)
1939-40	3,148	7.3	6,157,919	14,367	0.23
1940-41	3,647	2.1	7,250,857	4,093	.06
1941-42	4,113	1.7	8,198,890	3,477	.04
1942-43	3,946	1.7	7,322,423	3,214	.04
1943-44	5,594	1.2	10,320,341	2,150	.02
1944-45	7,492	8.1	13,572,315	14,604	.11
1945-46	8,590	5.5	15,821,538	10,214	.06
1946-47	7,681	1.4	14,386,624	2,713	.02
1947-48	8,384	1.7	15,720,848	3,218	.02
1948-49	7,343	1.0	14,337,737	1,994	.01
1949-50	8,629	31.8	16,442,402	60,388	.37
1950-51	8,737	31.2	16,519,138	59,044	.36
1951-52	9,151	32.0	17,481,991	61,000	.35
1952-53	9,058	28.3	17,409,299	55,820	.31
1953-54	9,868	9.0	19,338,138	17,772	.09
1954-55	9,908	9.7	18,813,933	18,359	.10
1955-56	10,036	7.1	18,846,032	13,326	.07
1956-57	9,738	1.5	18,225,178	2,892	.02
Totals	135,063	182.3	256,165,603	348,645	.16 (Average)

Table 4.—The distribution of lobster measurement samples by carapace size and moult classes.

Carapace size (*mm*)	Thousands of lobsters measured	Percent of total by sizes	Percent of total by moult classes
79.375	69	24	
82.55	64	22	83
85.725	59	20	
88.9	48	17	
92.075	20	7	
95.25	8	3	
98.425	5	2	14
101.6	4	1	
104.775	3	1	
107.95	2 }		
111.125	1 }	1	
114.3	1 }		2
117.475	1 }	1	
120.65	1 }		
123.825	—		
127.0	—		
Total	286	99	99

lobsters in the catch that becomes of legal size as a result of recent moulting (recruits), (b) the average growth rate, and (c) the probable natural mortality rate from sublegal to legal size. Annual gross fishing effort data were also compiled.

Natural and fishing mortality rate amount to approximately 83 percent for recruits and 86 percent for the more catchable next larger size (1st moult within the legal size range).

Table 4 shows total measurements in numbers and percent between the then minimum 79.375 mm and maximum 127 mm size limits.

From these measurements it was estimated that average annual natural mortality during the transition period from sublegal to recruit ranged from 28 to 36 percent and directly affected the abundance of those lobsters from minimum legal size to approximately 567.0 grams in weight.

It is evident from examination of carapace measurement records that a sharp break in the number of lobsters occurs between 88.9 mm and 95.25 mm. On the basis of observations, it is assumed this break represents the separation between moult classes of lobsters. It is further assumed that some in the 92.075 mm class are lobsters which by their most recent moult moved from sublegal to legal size. Conversely, it is assumed that others in the 92.075 mm class are in their second year of legal size and either failed to moult or did not increase in size as much as did the average.

The decrease in the number of lobsters between 88.9 mm and 92.075 mm appears to represent the overlapping separation between those groups of lobsters that have become of legal size as a result of recent moulting and those that have moulted at least once since they entered the legal size range. The 83 percent total represents the most recently recruited lobsters.

The next size group, those that have moulted at least once within the legal size range, amounts to 14 percent. The 2 percent group contains those that have moulted at least twice in the legal size range.

Differences in average size between lobsters in consecutive moult classes represent average growth rates in carapace length as a result of moulting. For example, differences in carapace length between size groups in the recruit class and their corresponding size groups in the next moult class are approximately 12.7 mm or 14 to 15 percent, indicating the average carapace linear increase.

The 4-yr measurements (1949-50 to 1952-53) correspond to the size distribution for the 1947-56 period (Table 5). Therefore, it is assumed the total sample covers enough years to eliminate significant differences in year class abundance. It appears probable that percentage differences between 79.375 mm and 82.55 mm sizes and between 82.55 mm and 85.725 mm represent true differences on the basis of average age and survival. Declines between 85.725 mm and 88.9 mm are not considered definitive because of the obvious scatter at the upper end of the recruit maximum size. Since these lobsters have been protected as sublegal lobsters during their previous year, it is assumed that differences in relative numbers represent natural or trap-induced mortalities at the equivalent of 3-mo intervals between the premoult sublegal and the postmoult legal sizes. Increased catchability characterizes increases in size to about 4 in. carapace (101.6 mm).[3]

When numbers are converted to percentages of the sample, it is evident that there is a consistent percentage reduction in the sample at 3.175 mm intervals from the minimum to the maximum legal size, with major declines at approximately 12.7 mm intervals. It is assumed that the major declines represent separation between moult classes and that there are approximately three and one-third moult classes within the legal size range.

The percentage composition of the recruit class under the former minimum legal size (3⅛ in. or 89.4 mm) is shown in Table 6.

[3]This analysis was made by D. M. Harriman.

Since the typical lobster during this high-temperature period moulted once each year, any difference among the first three 3.175 mm groups of the recruit class is indicative of the mortality rate within the class from sublegal to legal size. While a 12.7-mm carapace difference amounts to a year's growth, a 3.175-mm difference represents the equivalent of one-quarter of the moult increase or one-quarter of a year's growth. The 9 percent decrease between 79.375 mm and 82.55 mm and 7 percent decrease between 82.55 mm and 85.725 mm (Table 7) probably represent 9 and 7 percent mortality for the two size classes for one-quarter of a year. The relationship suggests that annual natural mortality for this age and size of lobster during the period covered ranged from about 28 percent to about 36 percent. Moult increment overlap between 88.9 mm and 92.075 mm size classes, by masking the moult group boundary, precludes the use of declines from 85.725 mm to 88.9 mm sizes for mortality estimates.

The decline in size frequency by percent shown in Table 7 suggests the probable mortality rate by size increments for the recruit class.

During this period (lobster years 1949-50 to 1952-53) average seawater temperature at Boothbay Harbor was about 10.4°C, nearly one-half degree higher than what appears to be the upper limit of the optimum range but more favorable than, for example, the 7.3°C average in 1967.

Mortalities among captive lobsters have generally been associated with moulting, particularly when moulting occurs coincidentally with higher temperatures. Predation and cannibalism under natural or seminatural conditions have also been observed to be greater at this time and appear to be related to greater activity by both lobsters and their predators. Discarding sublegal lobsters by fishermen, especially during

Table 5.—Number and percent of lobsters by lobster years.

Carapace size (mm)	1949-50		1950-51		1951-52		1952-53		Total number	Average percent
	Number	Percent	Number	Percent	Number	Percent	Number	Percent		
79.375	14,490	23.99	13,636	23.09	14,931	24.48	13,946	25.45	57,003	24.23
82.55	13,408	22.20	12,598	21.33	13,836	22.68	12,098	22.08	51,940	22.07
85.725	12,169	20.15	11,914	20.19	12,425	20.39	11,638	21.24	48,146	20.46
88.9	9,855	16.32	10,149	17.20	10,234	16.78	9,451	17.25	39,689	16.87
92.075	4,254	7.04	4,634	7.85	3,971	6.51	3,764	6.87	16,623	7.06
95.25	1,986	3.29	1,956	3.32	1,451	2.38	1,208	2.20	6,601	2.81
98.425	1,246	2.06	1,225	2.08	1,166	1.91	771	1.41	4,408	1.87
101.0	919	1.52	941	1.59	817	1.34	583	1.06	3,260	1.39
104.775	724	1.20	742	1.26	697	1.14	421	.77	2,584	1.10
107.95	447	.74	396	.67	413	.68	305	.56	1,561	.66
111.125	319	.53	309	.52	316	.52	206	.38	1,150	.49
114.3	213	.35	206	.35	247	.40	164	.30	830	.35
117.475	145	.24	146	.25	202	.33	115	.21	608	.29
120.65	116	.19	88	.15	156	.26	85	.16	445	.19
123.825	97	.16	104	.18	138	.23	65	.12	404	.17
Totals	60,388		59,044		61,000		54,820		235,252	

Table 6.—Size composition of recruit class samples in percent.

Carapace size (*mm*)	1949-50	1950-51	1951-52	1952-53	Average
79.375	29.03%	28.23%	29.05%	29.59%	28.97%
82.55	26.87	26.08	26.92	25.66	26.39
85.275	24.39	24.67	24.17	24.69	24.47
88.9	19.75	21.01	19.91	20.05	20.17

Table 7.—Percent decline in lobsters in recruit class by 3.175 mm intervals.

Carapace size (*mm*)	1949-50	1950-51	1951-52	1952-53	Average
82.55	7.47	7.61	7.33	13.25	8.88
85.725	9.24	5.43	10.20	3.80	7.30

the summer and fall, is in all probability a major source of natural mortality through the consequent predation by finfish and may be a principal cause of the estimated 28 to 36 percent natural mortality rate associated with this size class of lobsters.

Recent declines in the available supply and relative abundance of legal lobsters appear to be related to several factors. The decline in the frequency of moulting—or, at least, of the percentage of lobsters moulting each year—has reduced the volume of lobsters entering and passing through the legal size range. The length of time from egg to minimum legal size—a minimum of 4 yr and probably 5 to 7 yr for the majority—would appear to preclude prior to 1973 the effects being evident of unfavorable temperature or other environmental conditions on the supply of larvae and subsequent stock recruitment. Attenuation of time from larval to legal minimum has probably increased the mortality rate, since mortality is a function of time as well as of growth.

A third possibility is that of trap efficiency and the number of times during the lobster year that lobsters have to be exposed to trapping in order to provide an adequate sample of fishing mortality. If it requires 130 trap hauls per legal lobster per year when temperatures are optimum in order for the recruit class to supply 85 percent of the catch (660,000 traps at 9.15°C to produce 22 million lobsters), then at 7.5°C approximately 900,000 to 950,000 traps would be required to produce the same number of exposures. With lower temperatures lobster foraging activity declines; therefore, to provide compensating exposure to trapping would require increasing the number of traps.

"Trap exposure" and "trap haul" represent somewhat differing concepts. Although 75 percent of the annual catch consists of recently moulted lobsters produced by "trap hauls," the number of times these lobsters are "exposed" to trapping by reason of entering and leaving or remaining in traps or passing by will vary with foraging activity and shelter seeking. Presumably during low sea temperature years more traps will have to be set more times by fishermen to provide an equivalent proportion of opportunities for each lobster to be caught.

G. Disease, Pollution, and Predation.

Although there is no significant evidence to support the assumption and, in fact, all data indicate an opposite interpretation, factors other than seawater temperature and fishing effort may have caused the fluctuations which have periodically occurred in the supply of lobster. Among those factors are diseases, parasites, natural predators, and pollutants.

The factors causing death of lobsters in the ocean are not completely known, and the relative importance of those which are recognized is very much in doubt. Recognized as killers of lobster are: predation by fish, cannibalism, starvation, and predation by man (fishing). Possible but probably extremely rare in open water, is death by asphyxia (lack of oxygen) or chemical poisoning. These occur occasionally in commercial storage and handling of lobsters. In the "wild" state there are remarkably few diseases and parasites of the lobster. None of these is known to cause significant mortalities except under conditions of storage.

The most virulent disease is gaffkaemia, popularly called "red tail." The common name stems from an erroneous correlation of red pigmentation of the underside of the tail with infection. In fact, a wide variation of such pigmentation exists normally and is independent of the presence of the bacterium *Gaffkya homari** (now *Pediococcus homari.* Opinion 39. Rejection of the generic name *Gaffkya trevisan.* Int. J. Syst. Bacteriol. 21:104-105.)

Gaffkaemia customarily develops in lobster pounds where lobsters are held for extended periods under adverse conditions. The causative organism, a tetrad-forming encapsulated micrococcus, *Gaffkya homari,* reproduces in the blood until it is virtually a pure culture in the terminal stages.

Lobsters in the terminal stages of gaffkaemia are characterized by extreme weakness, a tendency to collect at the edges of a lobster storage pound in the shoalest water, and blood which lacks blood cells and does not readily clot. The behavior suggests that asphyxia might be critical in terminal stages.

More recent studies of gaffkaemia indicate that once established, the infection passes inevitably through the stages of infection to death. Contradictory indications exist in lobster pounds, where rates of infection among stored lobsters may soar in late summer and early fall. If no action is taken by the poundkeeper, evidences of infection decline with dropping temperatures and disappear by early winter. Losses in such situations may be inconsistent with the apparent degree of seasonal infection.

Gaffkya homari can be demonstrated in bottom sediments of lobster pounds, and at the height of the

1945-46 epidemic could be readily demonstrated in the open waters around Boothbay Harbor. It has also been cultured from the blood of stored and fresh-caught lobsters, even when blood smears were negative. Infection apparently requires a break in the integument.

One can make a very good case for pollution being an important contributory cause to the unfavorable environmental conditions normally associated with the blood bacterium, *Gaffkya homari*, which in some years has taken a very high toll of lobsters in storage and, in some areas, has been reported to occur extensively in "wild" lobsters.

Another disease is one called "shell disease," which is caused by chitinivorous bacteria which consume the outer layer of shell. A lobster's shell consists of three layers: an outer layer composed of chitin, chemically related to hair, fingernails, and hooves in mammals; a layer of crystalline calcium carbonate (lime) which gives strength and hardness to the shell; and the epithelium or living layer which produces both of these. Shell disease is caused by bacteria which eat away the chitin. The exposed calcium carbonate gradually dissolves, leaving the exposed epithelium. The resulting lesion may be very small, or may cover a large proportion of the shell. As the calcium layer is exposed, it erodes, leaving the soft endoderm exposed. Lesions may cover much of the shell, but do not appear to cause severe mortality except when gills are attacked. Then respiratory failure occurs. Shell disease may be endemic in certain locations and the infection can spread in a lobster pound. It appears to be a winter disease, perhaps because only lobsters removed in mid- or late winter are stored long enough to develop severe infections. Shell disease also requires an external injury to become established.

Another possible cause of lobster abundance decline is the long-term accumulation of commercial insecticides and their breakdown products from freshwater runoff and atmospheric fallout into the inshore ocean waters. Since lobsters are closely related to the insect pests being sprayed with chlorinated hydrocarbons, organic phosphates, and arsenical compounds, they are extremely sensitive to those control measures and high mortality rates have occurred when lobsters were inadvertently exposed to insecticides under normal storage conditions. Chlorinated hydrocarbons are persistent and highly toxic to Crustacea in trace dilutions (1 part in 5 billion has resulted in 100 percent kill of larval lobsters within 24 h) (Dow, 1972).

Biologists of the Maine Department of Sea and Shore Fisheries have been involved in research and experimental evaluation of insecticides and their effects on marine animals since September 1946. At that time a mimeographed bulletin was distributed to members of the fishing industry warning them not to expose live lobsters in any way to DDT. This warning was based on the results of laboratory experiments and field observations by the Bureau of Commercial Fisheries (now National Marine Fisheries Service) and Department biologists. Preliminary findings indicated that DDT is toxic to lobsters in concentrations of approximately 1 part in 10,000. Since that time it has been found that marine organisms are adversely affected by many pesticides, particularly the more recently developed chlorinated hydrocarbons and organic phosphates. DDT certainly is far less acutely toxic to lobsters than most chlorinated hydrocarbons, and the organic phosphates—malathion, sumithion, and parathion—appear to be even more toxic to Crustacea than many of the chlorinated hydrocarbons. Forty-three lobster samples, representing 54 lobsters, have been collected and processed. Thirty-nine samples, representing 93 percent, had measurable residues. Of the 39 positive samples, 17 were fresh-caught from inshore waters, and 15 were from lobster holding pounds. Six were from offshore, picked up by Bureau of Commercial Fisheries cruises, and one was a Magdalen Island sample from Quebec. Although the number of samples and the period of sampling would be inadequate for definitive conclusions, there is evidence of an appreciable increase in total residues (Fig. 3). Sampling has shown a decrease in toxic levels from the general source area seaward and from freshwater to tidewater, as indicated by representative species from the two environments. Sampling has indicated seasonal variations in residual levels of chlorinated hydrocarbons in representative organisms and a higher level of residual toxicity with time in the same areas.

Seasonal fluctuations associated with freshwater runoff are evident in the case of the soft-shell clams taken from Maine estuaries. During the 5 yr of sampling, the peak of DDT and its metabolites and dieldrin has been associated with high water flows between March and June. Minor increases in residues have also occurred coincident with fall rains, but in general residues have declined to trace levels by late summer and early fall.

Of the marine and estuarine species sampled since November 1965, all have produced traces of measurable amounts of DDT, its breakdown products, or dieldrin.

The first definitive association of DDT with lobster mortality in nature was in early 1966. A lobster from a holding pound with a high incidence of unexplained mortality and a record of nearby pesticide application over a period of years was analyzed for pesticide residues. This animal was found to contain 0.013 ppm DDT and 0.029 ppm DDE. The total residues, including DDT, its metabolites, and dieldrin, range from 0.042 to 0.635 in lobsters collected from this area. More extensive surveillance of the area has demonstrated an extensive pesticidal buildup not only in lobsters but in other marine organisms as well. It is presumed that pesticides contributed to the unusual lobster mortality rates of this pound, rates which did not decline significantly until aerial spraying was discontinued. Since higher concentrations have been found

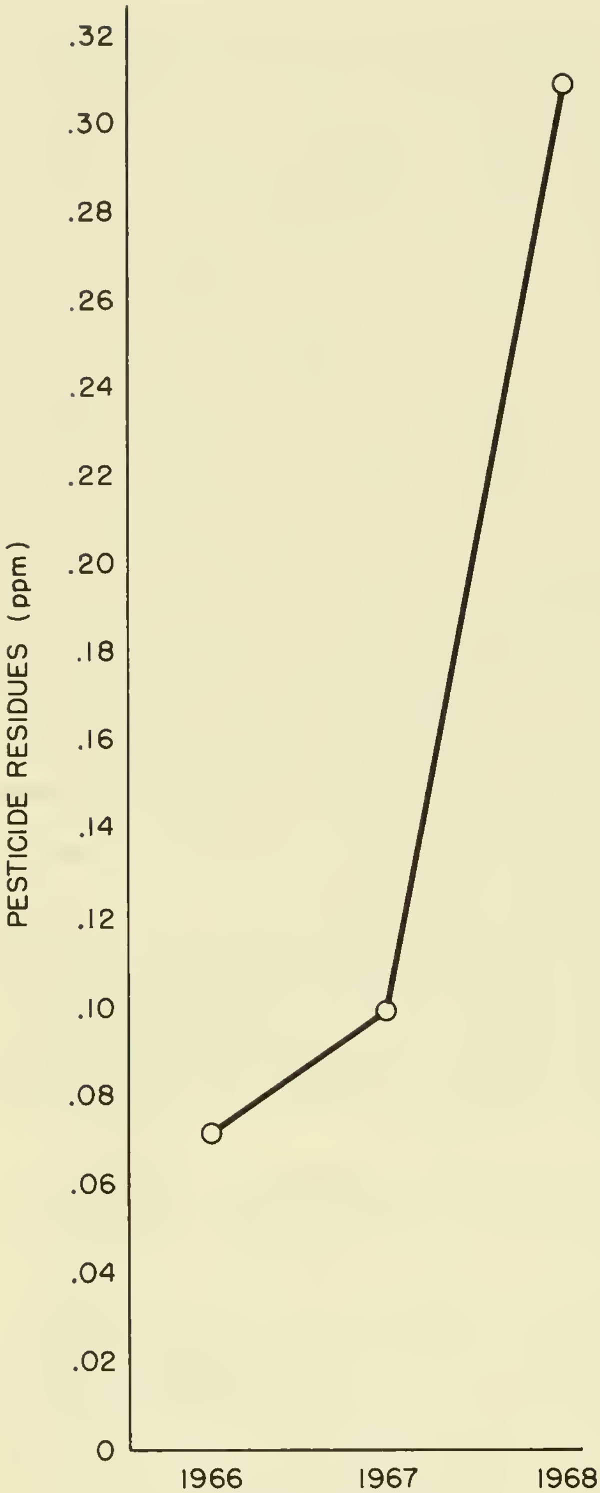


Figure 3.—Accumulations of pesticides in lobsters.

in fresh-caught lobsters, (up to 1.373 ppm), we assumed that insecticides are a major contributing factor in unexplained pound or tank-stored lobster mortalities.

Toxic levels for lobsters or other marine animals are unknown except under limited laboratory conditions. It is probable that tolerance varies among individual animals (as well as by species), and with other factors also, including temperature, salinity, and dissolved oxygen.

Detergents and other cleansing agents carried into seawater from household and commercial laundry facilities are also toxic to lobsters and may locally be a significant contributor to the "natural" mortality rate. Oil spills in Casco Bay have decreased the survival and marketability of lobsters.

Physical alteration of the environment by coastal dredging and filling, the destruction of tidal flats and coastal marshes and the damming of estuaries are all practices which have adversely affected lobster abundance by reducing the food supply and creating toxic conditions. One such well-documented harbor dredging occurence in 1959 resulted in a 32-fold increase in the mortality of stored lobsters within the period of a week.

Of those metals which have been evaluated copper causes the highest rate of mortality among lobsters. Although natural seawater contains this metal in measurable amounts, any appreciable increase in the copper content of water in which lobsters are held usually causes mortality of the animals. Temperature of the water appears to be an important factor in the rate of mortality from copper poisoning.

Among other evaluated metals naturally occuring along the Maine coast, zinc is probably the second most toxic. Since several toxic metals are used in industrial operations, pollution from these sources may very well be building up a lethal barrier for lobsters in some inshore areas. For this reason, mining in areas where metallic residues might be carried into tidewater poses threats to the lobster resource.

A summary of experiments measuring the relative toxicity of metals to lobsters is shown in Table 8, in which natural seawater and artificial seawater were both used to evaluate metals.

In these experiments four lobsters were placed in each tank containing about 182 liters of water. Air was bubbled through a hardwood plug to provide aeration and circulation.

The lobsters in the control seawater tank demonstrated their hardiness in the absence of crowding. In the first experiment the seawater controls lived 74 days in water temperatures ranging from 15° to 32.2°C. Death was caused when one lobster moulted, and the oxygen demand of the fouling reduced oxygen to lethal levels. Salinity of the water at this time had risen to over 80‰ because of evaporation.

The probability of such a limitation to lobster survival being ultimately developed in the inshore waters is very great when the various harmful materials are considered. Metals from either industry or mining, detergents from household or commercial use, insecticides, hydrogen sulfide from marsh or harbor dredging and other organic sources, and oil spills are all serious threats to lobster survival, especially in those

Table 8.—Average survival—days per lobster (three experiments combined).

Metal	Natural seawater	Artificial seawater
Copper	5	2
Zinc	17	19
Aluminum	19	31
Lead	30	27
Stainless steel	35	22
Control	65	45

waters adjacent to the shore or to tidal rivers where upstream sources may contribute toxic materials.

Organic materials or chemicals which impose a high rate of dissolved oxygen depletion are other survival threats to the lobster. These may include such diverse substances as sawdust, sulphite, and other chemical wastes from paper mills; domestic sewage; fish offal or chicken waste from processing plants; or mass mortalities of fish in tidewater and storm-loosened kelp which has been stranded in shallow and relatively warm water where decomposition is rapid. Even normally high seawater temperatures of summer accelerate organic processes and decrease dissolved oxygen.

"Calico" lobsters have bright yellow spots, which may appear on the carapace or dorsal surface of the tail. With dissection, each yellow spot (which is usually raised above the surrounding shell) is found to be underlain by a pustule located between the endoderm and mesoderm.[4] The pustule apparently does not prevent shell formation at moult, but does prevent the deposition of the red and blue pigments. The condition is a slowly developing one, occurring endemically in isolated areas. It does not develop in the periods of storage, and its effect on survival in the wild is unknown. Such lobsters can be held in captivity for many months with neither appreciable mortality nor visible change in development of lesions.

There is a class of infections which appear to develop at the site of wounds. They probably are caused by the same organism which infects claw plug wounds. Under conditions of long-term storage, pustules develop around the plugs, occasionally enlarging until the claw shell is eroded through from the inside. The contents of the pustule contain bacteria which are lethal if injected into the lobster's bloodstream.

Some lobsters have brown spots of varying sizes in the membrane on the underside of the tail. On close examination, each of these spots is found to surround a wound or puncture of the membrane. As the lesions develop, the membrane may erode, and loss of body fluids may occur. The condition varies from minor to lethal. Its contribution to natural mortality is unknown, but possibly significant.

These diseases are far more damaging to lobsters in captivity than in nature. In captivity lobsters are much more crowded, there is more opportunity for infection, and the weakening influences of the environment tend to reduce the lobster's resistance to disease.

Fresh water is often fatal to lobsters. Lobster tissue and blood are of about the same concentration as the surrounding seawater, and the lobster kidney is not able to maintain the internal concentration as the outside water becomes fresh. Therefore, as the salt content decreases, the lobster tissue takes up water to maintain the same concentration. If the water becomes too fresh, cells become so distended that they burst. With the organization of the body damaged, the lobster dies. The degree of freshness which a lobster can tolerate depends upon the rate of change in salinity, the temperature, and the amount of available oxygen. Seawater in the Gulf of Maine is normally about 32‰ salt. Lobsters begin to show symptoms of fresh water poisoning at approximately 20‰ salinity, or about two-thirds the concentration of seawater.

At times lobsters are overcrowded in pounds or floating cars. The supply of oxygen is then consumed and the lobsters are suffocated. Tanks using recirculated seawater are sometimes overloaded with the same results.

More often in tank systems, either using water pumped directly from the ocean or using recirculating water, a condition called "gas disease" (Harriman, 1954) causes trouble (Fig. 4). This disease occurs when too much nitrogen is dissolved in the water by the pump. Bubbles form in the lobsters, weakening and killing them. This condition is similar to the "bends" among human divers. Gas disease is more likely to develop in crowded tanks and in extremely warm or cold weather.

If the factors influencing the severity of the several lobster hazards are reviewed, it is found that in almost every case temperature is mentioned. The heavy losses of lobsters in warm water often raises a question, "How high a temperature can lobsters stand?" Lobsters have been successfully held in water of 30° to 38°C, and are often found on warmwater shoals. Any condition causing weakness in the lobster, however, is aggravated by high temperatures. Temperatures above 18°C are likely to give trouble in practical holding situations.

A sudden and drastic change of temperature or salinity, even within the tolerable range, will also weaken lobsters and cause death. Resistance to any given cause of weakness or death depends largely upon the suddenness of exposure, degree of exposure, and the number of such causes active at the time. Low oxygen combined with gas disease is far more deadly than low oxygen or gas disease alone, and the same relationships hold for other weakening conditions.

In addition to these frank pathogens, there are other organisms apparently commensal with the lobster. These include the mussel, barnacles *(Balanus balanoides)*, and, even in pounds, kelp and filamentous

[4]This was a special finding by D. M. Harriman.

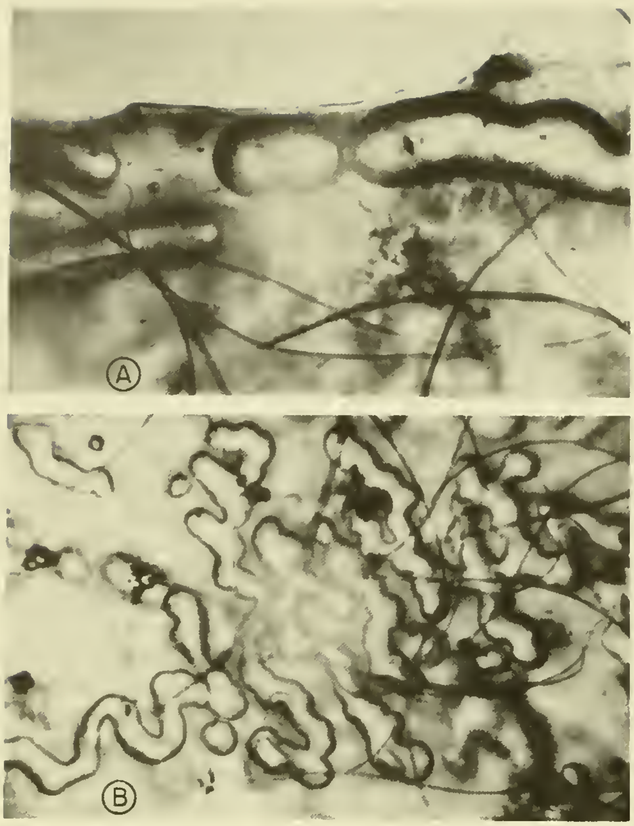


Figure 4.—Bubbles in the gill separators of a lobster. A. Major artery along the edge of the gill separator, with a large bubble. B. Sinus of the separator, showing a diffuse system of smaller bubbles. Both are at the same scale.

algae. Mussels setting on lobster gills frequently cause mortality.

Predation upon lobsters other than by man is probably most important in early life, especially during larval stages, and gradually becomes less important with increased size except when lobsters are confined together, as in traps. At any age or size the most hazardous time for a lobster is the period after moulting, before the new shell has hardened. Since larval stages float free in the water, they may be attacked by squid and by mackerel, pollock, and other surface-feeding fish. After the fourth moult the lobster goes to the bottom and seeks shelter. Thenceforth, it is the prey of cunners, sculpins, cod, cusk, hake, dogfish, sea robins, pollock, wolffish, and other fish found near bottom.

Lobsters not only need to avoid other fish, but other lobsters as well. In such an artificial home as a hatchery, one or two fourth-stage lobsters may be the only survivors of thousands started unless the water has been kept in motion to prevent cannibalism. Larger lobsters in traps are more likely to become victims of other lobsters immediately following moult.

Probably the most important predator on populations of commercial size lobsters is man. There is good reason to believe that in those areas which are intensively fished as many as 85 to 95 percent of the commercial size lobsters are caught or die naturally each year. In some locations even the higher figure may be exceeded.

Occasionally severe storms cause lobster mortalities. Evidence of this is furnished by lobsters in shallow inshore areas being washed ashore in traps and stranded by the ebbing tide. Small lobsters also are found in storm-loosened kelp and rockweed that has been stranded above mean high water.

Members of the Department's scuba team have reported many unbuoyed traps with entrapped lobsters. With the magnitude of annual trap losses and the durability of synthetic fibers, lobster losses from this source, both in terms of mortality and of removal from the fishery, may become of major significance if they have not already.

III. POPULATION DYNAMICS

A. The Available Biomass.

Considered collectively, the total lobster population of Maine and its contiguous waters consists of autonomous colonies dispersed about attractive ecological areas. Those lobsters of the *biological supply* which fall within the limits imposed by legislation constitute the *legal supply*. This supply is of paramount interest to fishermen, for a portion of these lobsters together with those illegal lobsters which enter and remain within traps and other fishing devices during the course of the calendar or lobster year make up a third supply—the *available supply* (i.e., those lobsters which are available for catching). The biological abundance of legal lobster can be estimated within ± 10 percent from effort-yield and temperature-yield data.

The most probable error in assuming an identity between relative abundance and the legal supply would involve the presence of islands of unfished lobster stocks, located in isolated rocks and shoals within or on the edges of the heavily fished bottom. Such a pattern would require careful planning to detect. It is, however, a pivotal issue in interpreting the meaning of other determinations.

Since the fishery appears to be carried on at a relatively high order of intensity, 90 percent or more, the legal supply is largely dependent upon those previously sublegal lobsters which became legal as a result of moulting and comprise the recruited supply. For biological and meteorological reasons, it is assumed that the available portion of the biological supply varies seasonally and geographically as well as by sex, age, and probably other factors. *It is now becoming increasingly evident that nearly all of the available legal population is being caught each year.* In reference to "legal" size lobsters there are several compelling arguments for an increase in the minimum legal size of lobsters to 3½ in. (88.9 mm) or more. Taylor (unpublished data) measured two lots of egg lobsters at Boothbay Harbor; one of 66 (1948-49) and the other of 243 (1950). In the smaller lot, animals were grouped by 1/32 in. (0.79 mm) intervals; in the larger, by ¼ in. (6.35 mm) intervals. Of the 66-lobster sample, 7 (10.6 percent) were 3½ in. (88.9 mm) or smaller in carapace size. Of the 243-lobster sample, 11 (4.5 percent) were 3⅝ in. (92.1 mm) or smaller. More recently Krouse (1973) found that only 11 percent of 1,150 eggbearing females were 3½ in. (88.9 mm) or less in carapace length. The consistency of these results covering a period of 25 yr appears to be an adequate demonstration of what probably will prove to be minimal spawn stock requirements for maximum continuing catch in the lobster fishery.

Estimates of net weight increment with larger minimum sizes have been made periodically by departmental research personnel since 1951 and range from 3 to 5 percent with each 1/16 in. (1.6 mm) increment to 3½ in. (88.9 mm) and 3⅝ in. (92.1 mm). *If these estimates are valid, a minimum legal size of 3½ in. (88.9 mm) would result in 15 to 18 percent net increase in total landings; at 3⅝ in. (92.1 mm) the net increase might well be an additional 6 to 10 percent.*

Two major objections made by fishermen to size increases are (1) a probable increase in illegal lobster meat and (2) the "ordinary" person in terms of income could not afford larger, more costly lobsters. These same objectors fail to realize the necessity for fisheries employees to maximize their earnings if the relative exclusiveness of the fishing industry is to be justified.

Older fishermen will sometimes argue: "We had a 3½ in. minimum years ago and no one could make a living." The argument is spurious since landed value was the principal factor influencing landings during the economically depressed inter-World War I and II period. Deflated prices paid fishermen for lobsters during the 1919-1942 period averaged 6.8¢ per pound less than in 1916, a decline of 31 percent in real landed value. The average annual catch in these years was 6.8 million pounds (3,100 metric tons), a decline of 33 percent from the 10.2 million pound (4,600 metric ton) catch of 1916. The 1943 average price increased to the equivalent value of 1916 and catch increased to an annual level of 11.5 million pounds (5,200 metric tons), 29 percent higher than the highest annual catch made between 1919 and 1942. Typical of what happened are the relationships among effort, temperature, and landings (Table 9).

The total number of traps fished each year is the only available long-term indicator of effort. General increases or declines in the number of traps are influenced by changes in demand (see Section IV-A) as indicated by fluctuations in the price paid fishermen for their catch. Thus, price is a function of demand, while the total number of traps being fished is a reflection of that demand in terms of effort. It can be concluded that trends in the number of traps over several consecutive years are reliable indices of gross fishing effort (see Fig. 5).

Table 9.—The relationships among effort, temperature, and lobster landings.

Year	Mean annual seawater temperature		Effort		Catch
	°F	°C	Thousands of traps	Millions of pounds	Thousands of metric tons
1940	44.6	7.0	222	7.6	3.4
1906	44.7	7.1	305	15.0	6.8
1965	45.8	7.7	789	18.9	8.6
1924	45.9	7.7	154	5.5	2.5
1935	46.7	8.2	185	7.7	3.5
1930	46.8	8.1	205	7.8	3.5
1948	46.7	8.2	459	15.9	7.2
1964	46.9	8.3	754	21.4	9.7
1945	47.1	8.4	378	19.1	8.7
1959	47.0	8.3	717	22.3	10.1
1946	47.3	8.5	473	18.8	8.5
1961	47.3	8.5	752	20.9	9.5
1958	47.4	8.5	609	21.3	9.7
1933	47.5	8.6	180	5.9	2.7
1947	48.6	9.2	516	18.3	8.3
1956	48.6	9.2	533	20.6	9.3
1949	50.1	10.1	462	19.3	8.8
1955	50.0	10.0	532	22.7	10.3

During years of low landings when fishing effort and seawater temperature are approximately the same, differences in landed value appear to be the principal factor influencing differences in catch (Table 10).

B. Recruitment.

Sample measurements have indicated that the catch has become increasingly dependent upon recruitment by moulting of previously sublegal lobsters. In 1947 only 79 percent of the catch consisted of newly recruited lobsters; by 1953, previously sublegal recruits made up 86 percent of the catch. Sampling of the catch in York County in 1949 and 1950 indicated that in those years the number of recruits in the catch averaged 90 percent as compared with 83 percent for all Maine coastal counties, suggesting that the present intensive level of fishing effort coastwide had been experienced in York County two decades earlier.

C. Yield, Fishing Effort, and Seawater Temperature.

Interacting factors of fluctuating seawater temperature influencing supply and variable fishing effort

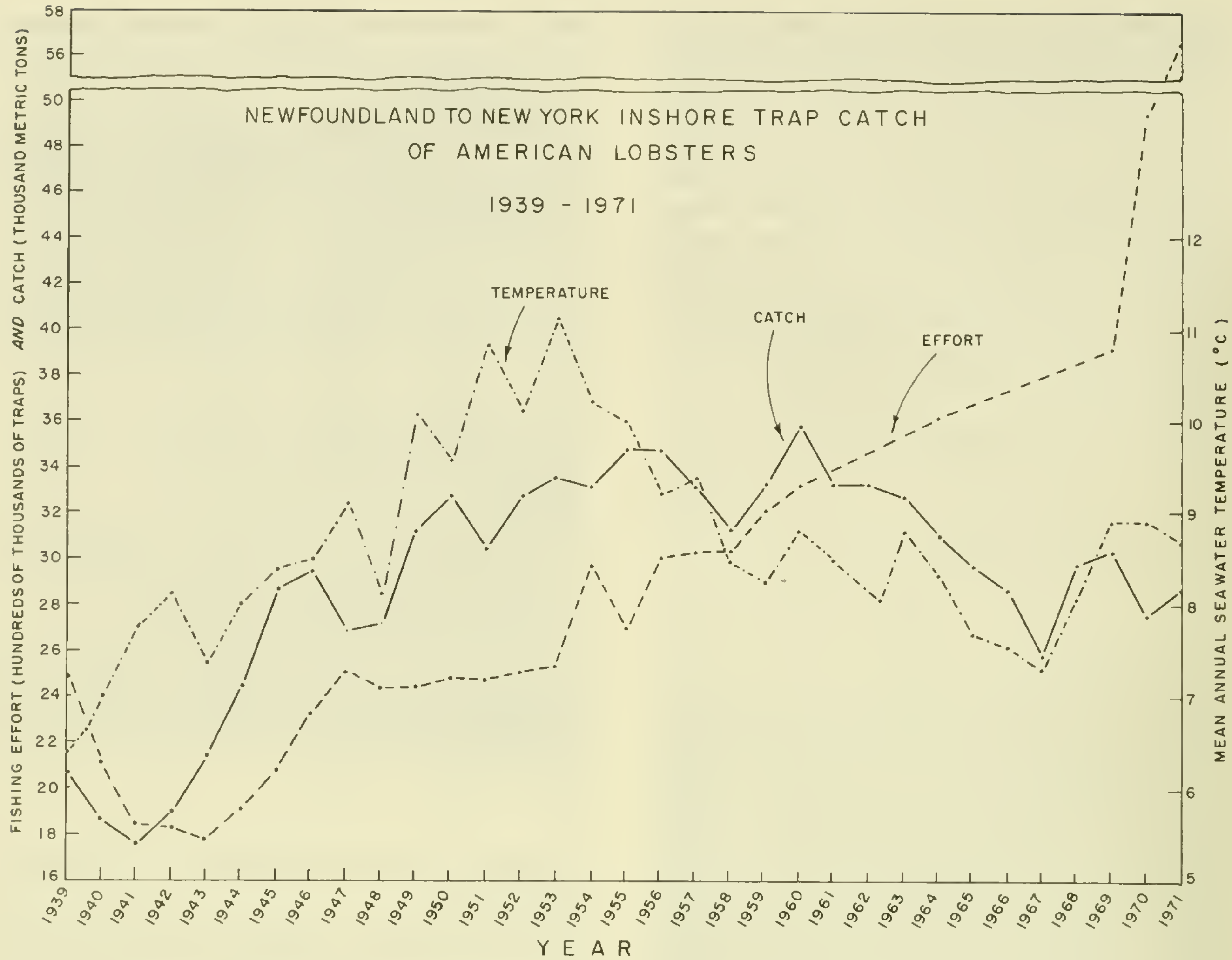


Figure 5.—Relations between numbers of traps and landings, Newfoundland to New York, and Boothbay Harbor temperature (°C), 1939-71.

affecting yield have been evident throughout the history of the Maine lobster fishery (Dow, 1966).

In more recent years when sea temperature has been approximately the same, catch has decreased despite comparable or even increasing effort (Table 11). These declines appear to be indicative of the effects of overfishing. This will be discussed below in some detail.

Catch, fishing effort, and other related data had been gathered sporadically and differentially by the State of Maine from the establishment of the Department of Sea and Shore Fisheries in 1885 to World War I. Scattered records of annual catch were reported after 1843 when commercial canning operations were developed. Detailed information of the annual catch was first made in 1880 when landings were 6,457 metric tons. In 1887 the catch was nearly 10,000 metric tons, and in 1889 the all-time record catch of 11,091 metric tons was made, a total of only 22 metric tons more than the second highest year of 1957.

After 1889 annual production steadily declined for approximately 15 yr. Consecutive year data of more than 5 yr were first reported beginning with 1897. Between 1919 and 1938 information was irregularly collected by the department and the U.S. Fish and Wildlife Service independently, and since 1939 by both agencies collaborating in a continuous data recording program.

A study made by the Department of Sea and Shore Fisheries of three fishing areas indicated that catch per trap is not a valid index of abundance. During the time of this investigation, a total of 807 daily trap hauls produced 2,055 lobsters, or an average of 2.546 lobsters per trap haul, while a total of 2,505 set-over trap hauls produced 6,323 lobsters, or an average of 2.524 lobsters per trap haul. The importance of the data is in the information they furnish in catch per unit of gear as an index of population abundance. An average of 11 daily trap hauls made during 71 fishing days in all months except January, June, and July produced 2,055 lobsters. An average of 13 set-over trap hauls made during 198 fishing days in all months except July pro-

Table 10.—Effect of price differences on lobster catch when effort and sea temperature are approximately the same.

Year	Mean annual seawater temperature		Effort	Catch		Average landed value
	°F	°C	Thousands of traps	Millions of pounds	Thousands of metric tons	Cents per pound
1932	46.8	8.2	208	6.1	2.8	.18
1928	47.0	8.3	211	7.1	3.2	.28

Table 11.—Changes in catch in years in which temperatures were approximately the same, effort comparable or even increasing.

Year	Mean annual seawater temperature		Effort	Catch		Change
	°F	°C	Thousands of traps	Millions of pounds	Thousands of metric tons	Percent
1959	47.0	8.2	717	22.3	10.1	
1964	46.9	8.3	754	21.4	9.7	− 4.0
1958	47.4	8.5	609	21.3	9.7	
1961	47.3	8.5	752	20.9	9.5	− 1.9
1960	47.9	8.9	745	24.0	10.9	
1963	47.9	8.8	731	22.8	10.3	− 5.0
1969	48.0	8.9	805	19.8	9.0	−13.2
1970	48.0	8.9	1,166	18.2	8.3	− 8.4
1971	47.7	8.7	1,264	17.6	8.0	− 3.4

duced 6,323 lobsters. Although the catch per trap per day was slightly lower for those traps fished on a set-over basis, the total catch for the year was 2.8 times greater. Average trap haul catches were greater for set-over fishing during October, November, March, April, and May, while daily haul catches were greater in August, September, December, and February. It is doubtful, however, if these results have any significance as far as seasonal differences are concerned. Too many other factors, including weather conditions and demand, influence fishing effort and would, thereby, modify results. Results of this study indicate that set-over fishing has no catch per trap advantage over daily fishing (2.524 to 2.526 per trap haul) and catch per trap remained nearly as high during 198 fishing days (2.524) as it did during 71 fishing days (2.546). *It may, therefore, be concluded that annual catch per unit of gear is more an index of the number of fishing days than it is of fluctuations in year-to-year abundance.*

Although catch per unit of gear cannot be used as an index of abundance, the number of traps fished can be used as an approximate index of gross fishing effort.

In years when seawater temperatures are approximately the same, differences in catch have been associated with differences in effort. *In addition to being the most reliable index of gross fishing effort, the average annual number of traps being fished is the longest history of recorded effort data available, consisting of 55 individual years spanning the period 1897-1971.*

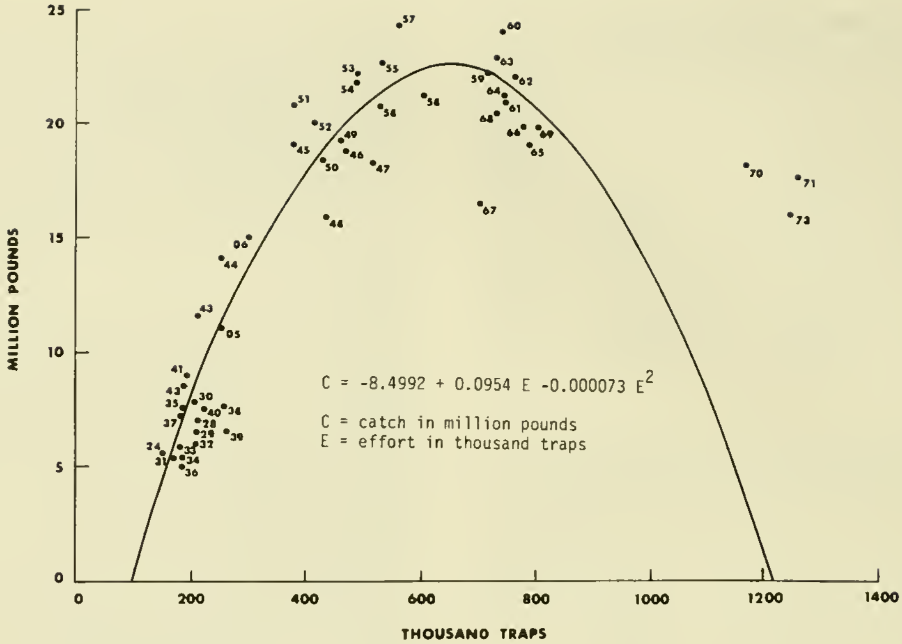
These data have been plotted as an effort-yield curve (Fig. 6). Using the available data on catch, fishing effort, and temperature the yield functions shown in Table 12 were compiled.[5] According to the catch-effort function (without the inclusion of seawater temperature as a variable) the maximum sustainable yield (MSY) from the Maine lobster fishery is estimated at 22,108,200 pounds [equation (2)]. This catch can be caught by the equivalent of 642,000 pots hauled 130 times during the year. The actual number of pots fished in 1970 was 895,000 and in 1972 more than 1.2 million. On the basis of these calculations, there is a strong indication that the Maine lobster resource is significantly overfished.[6] We also felt that the yield equation should be computed with the inclusion of seawater temperature as an independent variable influencing the catch. (See Fig. 5 for fluctuations in all these variables.) The results indicated that seawater temperature within the observable range has a positive influence in the level of the catch and was statistically significant at the 1 percent level. (See Fig. 7 for actual and predicted catch.) Using the 1970 seawater temperature, the maximum sustainable yield was estimated to be 22,021,000 pounds [equation (1)]. The catch is estimated to require 667,000 pots. Although the pots fished series is a crude proxy for fishing effort, the above analysis does indicate a significant trend toward overfishing.

Effort trends throughout the major lobster producing areas of the Northwest Atlantic are similar to those observed in Maine (Fig. 5).

The limit of Maine lobster supply when the resource is being intensively fished correlates very well with seasonal fluctuations in seawater temperature. Although seasonal temperatures appear to be more influential than annual averages, it is necessary to use annual averages to compare conditions in different years as well as to compare climatic trend influences on different species.

[5]The years 1971 and 1972 were omitted from the regression because of their extreme deviation from the traditional Schaefer model. (See footnote 6 for further explanation.) In addition, a reviewer of this manuscript has commented as to whether one can get a long-run equilibrium curve using annual data, but admits that it will serve as the best approximation available.

[6]Observations from 1970-72 certainly do not seem to conform to the traditional Schaefer parabolic models. When further observations are obtained the reader may want to apply two other steady state models which allow for a flatter yield function. See Pella and Tomlinson, 1969 and Bell, Carlson and Waugh, 1973.



Note: Two-digit numbers indicate years

Figure 6.—Relation between catch and fishing effort (traps) for the inshore American lobster fishery, 1905-72.

D. Dynamic Pool Models.

Thomas (1973) has applied the yield per recruit model to the Maine lobster fishery. Depending on the methodology, the instantaneous total mortality *(Z)* ranged from 1.1363 to 2.9188 while the instantaneous natural mortality *(M)* ranged from 0.0202 to 0.3467. *Therefore, the estimates of the instantaneous fishing mortality (F) ranged from 0.7896 to 2.8986.* According to Thomas, the lower natural mortality and higher fishing mortality were more plausible. In order to complete the necessary inputs for the dynamic pool model, Thomas computed the following equations:

$$\hat{L}_t = 266.77\ [1-e^{-0.04785\ (t\ +\ 0.7725)}]; \quad (1)$$

$$W = 0.001682 L_t^{2.82826}. \quad (2)$$

Equation (1) relates the length of the lobster *(L)* to age or time. This is essentially the growth function for lobsters. Equation (2) relates the lobster weight *(W)* to length. Based upon the above equations Thomas' estimates of M (instantaneous natural mortality); W_∞ (maximum expected weight); K (constant proportional to catabolic rate); t_0 (hypothetical age at zero weight); t_c (assumed age at first capture); t_r (assumed age at

Table 12.—Estimated relation between catch, effort, and seawater temperature for the Maine lobster fishery (yield functions).[1]

Equation	R^2	Years	MSY (lbs.)	E_{max} (traps)	D.W.
(1) $Q = -35.6442 + 0.0814E - 0.000061E^2 + 0.6363T$ (10.96) (8.16) (3.85)	0.933	1905-06, 1924, 1928-70	22,021,300	667,000	0.97
(2) $Q = -8.4992 + 0.0954E - 0.000073E^2$ (12.80) (9.12)	0.909	1905-06, 1924, 1928-70	22,108,200	642,000	1.19

t-values in parentheses

Q = Catch in million pounds
E = Effort in thousand traps
T = Annual seawater temperature °F for Boothbay Harbor

[1]The years 1897-1904 were omitted from the regression since no observations on seawater temperature were available.

Source: Data from Sea and Shore Fisheries. See Appendix B.

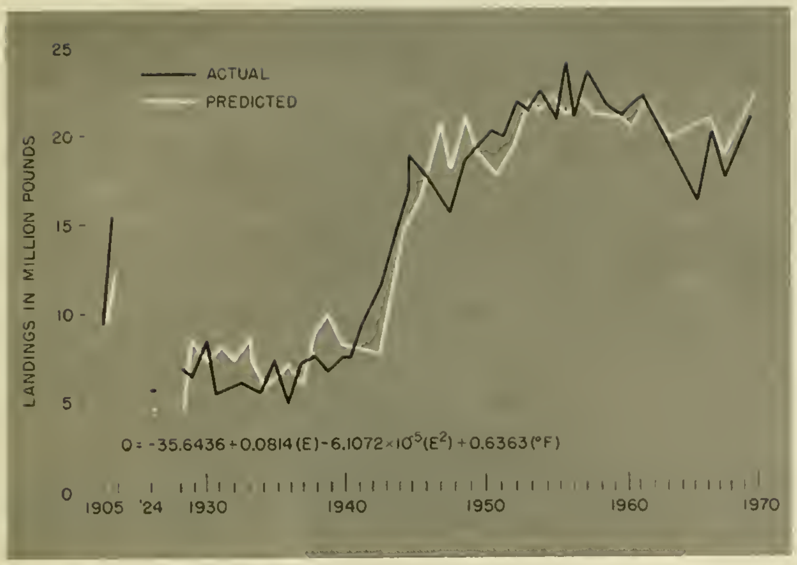


Figure 7.—Actual and predicted landings of Maine lobsters, 1905-06, 1924, and 1928-70.

recruitment) under six sets of combinations, we computed the curves shown in Figure 8. Notice that the maximum yield per recruit for all six functions occurs between an instantaneous fishing mortality of 0.10 and 1.50. The observed F ranges from 0.7896 to 2.8986 with the latter figure probably closer to reality. According to Cushing (1968), it is wrong for fishermen to exploit a stock at a point beyond or to the right of the maximum yield per recruit. It is quite apparent that the Maine lobster fishery is overfished, based upon Thomas' work and Cushing's criterion. Thomas further recommends that the legal minimum size should be raised to at least 89 mm (3½ in.) carapace length.

E. The Overcapitalization of the Fishery.

It is quite apparent that the Maine American lobster resource is overcapitalized. Overcapitalization is defined as a condition where the index of inputs of vessels, fishermen, and technology into a fishery is greater than that necessary to harvest maximum sustainable yield, surplus yield, or maximum yield per recruit. It is quite apparent that based upon both the

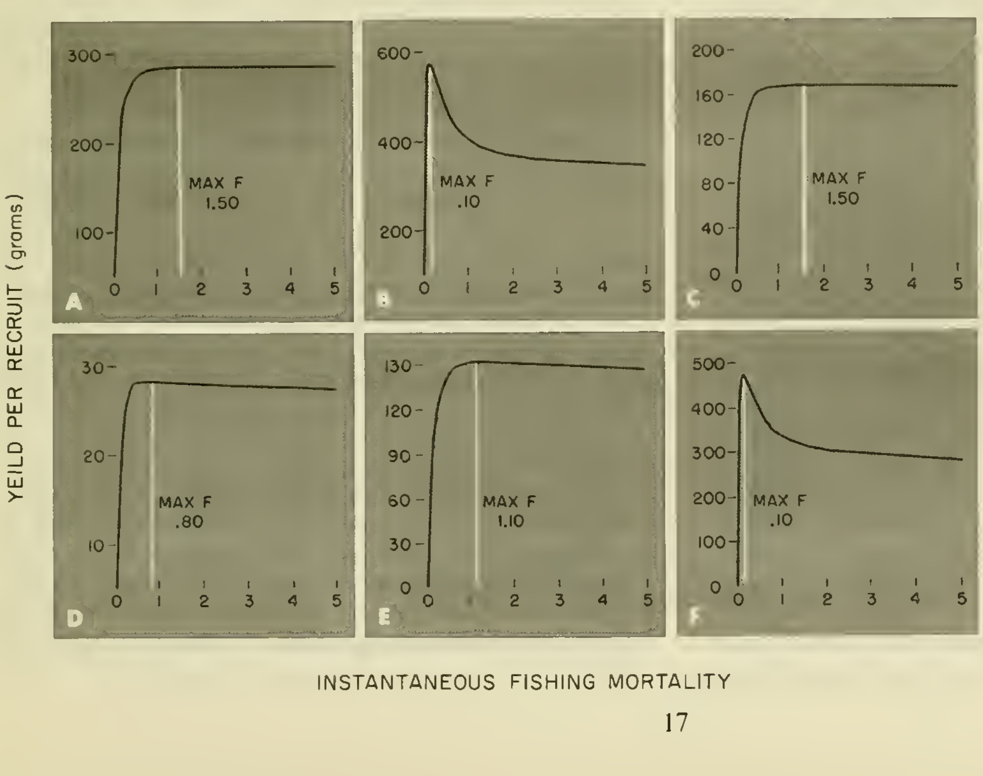


Figure 8.—Relation between yield per recruit and instantaneous fishing mortality under various parametric assumptions for the inshore American lobster.

catch-effort function and the yield per recruit relation for Maine American lobsters that this fishery is grossly overcapitalized. With this much said, let us now turn to some of the economic forces that have produced overcapitalization.

IV. ECONOMIC RELATIONSHIPS

A. The Growth in the Demand for Lobsters, 1950-69.

Consumer demand for fishery products is the driving force behind the expansion of a fishery which leads, on occasion, to overfishing. Over the 1950-69 period, U.S. per capita consumption of all lobsters (American, spiny, etc.) increased from 0.585 to 0.999 pounds (live weight). The rate of growth in per capita consumption was approximately 2.4 percent per year. This was in sharp contrast to overall U.S. per capita consumption of food fish, which remained relatively constant over the same period at 10 to 11 pounds. The increased consumption came primarily in the important spiny lobster category. The rapid growth in the consumption of lobsters produced a rise in ex-vessel prices of 4.8 percent per year, which exceeded the growth in all consumer prices, which averaged 1.7 percent per year. What were the determinants of the per capita consumption of lobsters? A statistical analysis was made in which the following factors were related to per capita consumption of all lobsters:

1. ex-vessel price of American lobsters relative to the general price level in the U.S. economy; and
2. real per capita disposable personal income (standard of living).

In prior statistical tests, it was found that crab and shrimp prices as well as meat and poultry prices were not significantly related to the per capita consumption of lobsters. It was anticipated that per capita consumption of lobsters would fall if ex-vessel prices increased faster than the general price level and would rise owing to increasing real per capita income. Figure 9 shows the estimating accuracy of our statistical equation, which is consistent with our expectations. This relates the per capita consumption of all kinds of lobsters to ex-vessel prices and per capita income over the 1950-69 period. According to the analysis, a 10 percent increase in lobster prices will reduce per capita consumption by roughly 3 percent. However, a 10 percent increase in per capita income would increase per capita consumption about 17 percent. The consumer demand analysis for lobsters indicated that despite rising lobster prices, per capita consumption increased owing to the rise in the standard of living. This provided strong economic incentive to expand the domestic lobster fisheries.

B. Distribution of Lobsters.

About 87 percent of the Maine American lobster catch is distributed live. Fishermen sell to local buyers, retail trade, and large dealers. Table 13 shows the estimated markup of lobster prices over the ex-vessel level over the 1959-71 period. Unfortunately, retail prices are only available through 1967 at New York City. Over the 1959-67 period, lobster fishermen have been getting an increasing share of the final retail price. The wholesale and retail markup has been declining somewhat as indicated by the figures in Table 11. It must be concluded that cost pressures are coming proportionally more at the ex-vessel level than at wholesale or retail.

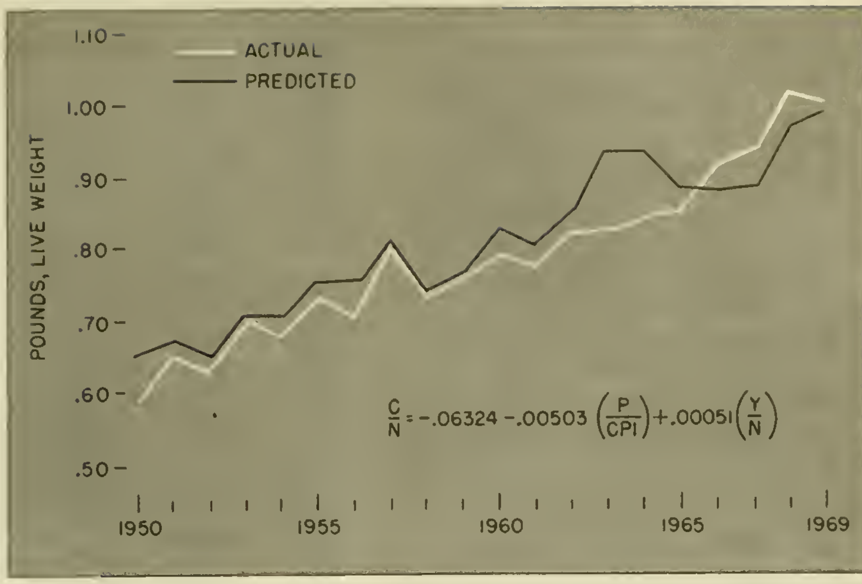
On the average, the wholesaling function has added approximately 43.5 cents to the price of lobsters over the ex-vessel level while the retailing function has added 26.6 cents to obtain the final price.

C. Regional Consumption of Lobsters.

A consumer survey panel, consisting of representative households throughout the United States, recorded their fishery product purchases for a 12-mo period, beginning in February 1969. They were participants in a study conducted under the aegis of the National Marine Fisheries Service (formerly Bureau of Commercial Fisheries), Economic Research Laboratory. Part of this study concerned itself with the consumption of lobsters. We thought it might be helpful to look at some of these relationships.

New England households, according to the survey, account for nearly two-thirds of lobsters purchased for consumption at home. Most of the remaining one-third of lobster purchases are made in the Middle Atlantic and South Atlantic regions (Fig. 10). Home consumption in all other regions is insignificant, with the exception of the East South Central area, which accounts for just under 5 percent of the total. The figures represent fresh lobster and consist chiefly of American lobster. It is likely, however, that some of the quantity attributed to the southern area states represents local spiny lobster.

New England's predominance in at-home lobster consumption reflects the difficulties, and high cost, of shipping live lobsters from the producing areas. Tradition, of course, insures a strong local market for limited supplies of American lobsters. It should be noted, however, that the survey also revealed that home consumption of lobsters represents only 40 percent of the total quantity consumed in the United States. Thus, with restaurant consumption taken into account, the regional distribution may not favor the New England area quite so heavily. Nonetheless, the important inference to be drawn from the at-home consumption distribution is that out-of-area retailers are reluctant to assume the risks of marketing live lobsters, which are highly perishable outside their normal environment. Consequently, in the event that lobster production should be increased—and this is a possibility with deep-sea lobster fishing—improved ways of handling lobsters will be needed to enhance retailers' dispositions toward marketing the product.



$\frac{C}{N}$ = PER CAPITA CONSUMPTION OF ALL LOBSTERS

$\frac{P}{CPI}$ = REAL EX-VESSEL PRICE (OR ACTUAL EX-VESSEL PRICE OF LOBSTERS DIVIDED BY CPI (1967 = 100)

$\frac{Y}{N}$ = REAL DISPOSABLE INCOME PER CAPITA

Figure 9.—Actual and predicted per capita consumption of all lobsters, 1950-69.

Since 1946 when the first frozen whole lobsters were marketed similar products of varying degrees of acceptability have been processed and sold in the less accessible market areas of the United States and in Europe.

Frozen lobster tails, which are mostly foreign imports, are consumed most heavily in the Middle Atlantic region. Per capita consumption of lobster tails in the Middle Atlantic is 1.6 times the U.S. average for at-home consumption, and the area accounts for 29 percent of the total consumed in the U.S. The East North Central states consumed 27 percent of the U.S. total, and their per capita rate is about 1.4 times the national average. The East South Central region also is a major market for lobster tails, and accounts for 16 percent of the total consumed at home (Fig. 11).

Not surprisingly, consumption of frozen lobster tails is low in New England, what with the availability of local supplies of American lobsters. Consumption also is low (almost insignificant) in the West Central states, both North and South. Beyond this belt, however, lobster tail consumption picks up considerably and in the Mountain areas the per capita rate is 1.5 times the national average. There are also significant quantities consumed in the Pacific states, which account for 8 percent of the U.S. total, although the per capita rate is only 61 percent of the national average in that area.

D. Costs and Earnings of Lobster Boats.

(1) Data Source—Data are not collected on a systematic basis on the earnings of lobster boats. Fortunately, we do have data collected by Professor Andreas A. Holmsen of the University of Rhode Island. These data pertain to the operations of the New England trap-lobster fishery (Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine). A sample of 186 boats was collected (126 operating out of

Table 13.—Ex-vessel, wholesale, and retail prices and markups for American lobsters, 1959-71.

Year	Price: Ex-vessel	Price: Wholesale	Price: Retail	Fishermen's share of retail price	Markups: Wholesalers	Markups: Retailers
	- - - *Cents per pound* - - -			- - - *Percent* - - -		
1959	50.10	87.00	102.00	49.12	42.41	14.70
1960	45.70	77.00	99.00	46.16	40.65	22.22
1961	53.20	86.00	117.00	45.47	38.14	26.50
1962	50.70	82.99	113.00	44.87	38.91	26.55
1963	55.40	86.00	109.00	50.82	35.58	21.11
1964	66.20	98.00	121.00	54.71	32.45	19.01
1965	75.20	120.00	147.00	51.16	37.33	18.37
1966	74.87	116.11	145.01	51.63	35.52	19.93
1967	82.50	127.00	151.00	54.64	35.04	15.90
1968	73.95	132.13	n.a.	—	44.03	—
1969	88.09	133.00	n.a.	—	33.77	—
1970	99.20	153.99	n.a.	—	35.16	—
1971	108.40	178.99	n.a.	—	39.44	—

Source: Economic Research Division, NMFS.

Maine) for the year 1967. This represents approximately 2.7 percent of the universe of 6,778 boats. Data were collected on such items as gross stock; variable expenses; fixed expenses; physical characteristics of boats; utilization of boats; and socioeconomic characteristics of the fishermen.

(2) **Determinants of Production Among Lobster Boats.**—Using our sample of 186 boats for 1967, we attempted to explain the variation in annual landings of lobsters among the boats. It was hypothesized that a number of factors might be responsible for variations in annual production of lobsters by boat:

(a) Boat Size: Larger boats may be capable of greater range and storage capacity;

(b) Boat Age: If not adequately maintained, older vessels might be less productive;

(c) Boat Horsepower: Horsepower increases range and ability to fish in rough weather as well as speed in hauling traps;

(d) Number of Traps Fished: The more traps used the larger the lobster catch;

(e) Number of Trips: Probably the most important variable in influencing the total lobster landings of any boat is the time utilized for fishing during the year;

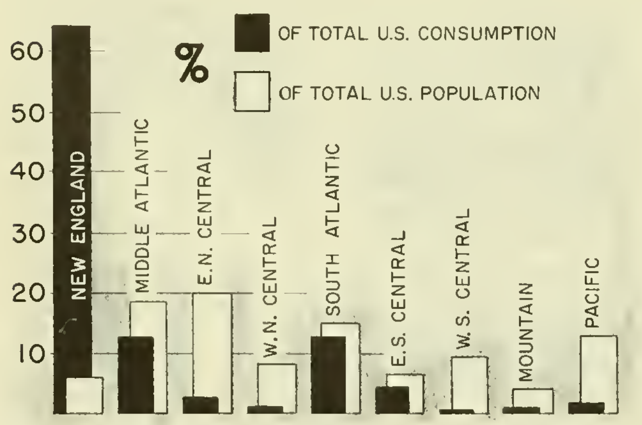


Figure 10.—Regional distribution of lobster consumption (at home) and population, 1969.

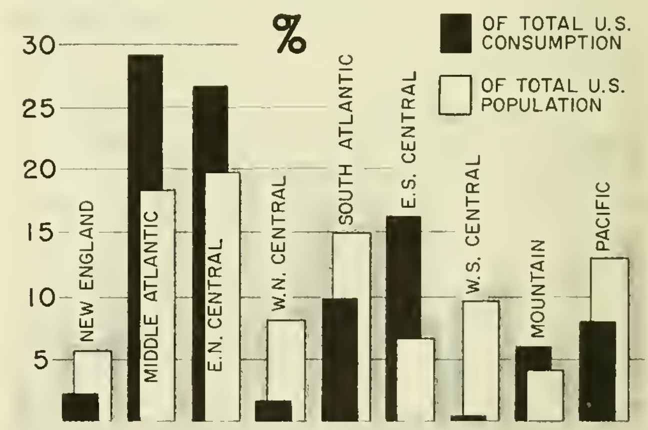


Figure 11.—Regional distribution of lobster tail consumption (at home) and population, 1969.

(f) Distance Traveled to Grounds: Greater distances traveled would be compensated by larger catches.

Of course, there are probably other factors that determine the annual production of lobsters, notably, "the good captain" hypothesis. That is, the experience and capability of the captain or boat owner may greatly influence the annual production, *ceteris paribus*. To explore some of the hypotheses listed above, we ran a regression of annual lobster landings against the various boat characteristics and operating patterns. This is shown in Table 14. Although boat size, age, and distance to the grounds were statistically significant variables (at the 5 percent level) in "explaining" annual production, the number of traps fished and fishing trips were more significant, as indicated by their t-values. Horsepower exhibited a negative sign which is inconsistent with the theoretical hypothesis. The $\overline{R}^2 = 0.74$ for the equation used to "explain" annual production is fairly good.

(3) Determinants of the Cost of Production.—Many of the costs commonly associated with running a lobster boat operation are related to the physical characteristics of the operation as well as pattern of operation. Table 14 shows the relation between various components of costs (i.e., fuel and oil, bait, salt, and ice, etc.) and hypothesized determinants of these costs. Generally, physical characteristics are poor predictors of costs. For example, fuel and oil cost per annum was hypothesized to be linked to (1) boat size: (2) horsepower; (3) number of lobster traps; and (4) distance from grounds. However, the $\overline{R}^2$ was only 0.16.

(4) Returns to Boat and Lobsterman, 1967.—For the inshore American lobster fishery, returns to capital (i.e., vessel) are difficult (if not impossible) to distinguish from returns to labor (i.e., the vessel owner as a lobsterman). For the most part, the lobster firm is a one-man operation where the owner is also the worker. However, some lobster boat owners do employ helpers to work along side them. Using the 186 boats in our sample, we see a breakdown of revenues, costs, and returns to boat and lobsterman in Table 15. The average boat earned approximately $10,460 (revvenue) per year from fishing (unadjusted for weeks or hours lobstering) and incurred costs of $4,439 leaving returns of $6,021 to boat and lobsterman. However, these figures may be very misleading since they include boats that vary greatly in their weeks lobstering. What we desire are earnings per week or hour so that we can make interfirm comparisons. To do this we divided for each firm the total returns to boat and lobsterman after deduction of costs shown in Table 15 for each boat by weeks lobstering. This yielded returns to boat and lobsterman per week. Figure 12 shows a frequency distribution of weekly returns. The average returns were $125.50 per week. This can be compared with weekly wages in manufacturing for the State of Maine of $93.07 (1967). The figures, of course, are not strictly comparable since the returns to lobstermen also involve returns to capital invested in the boat and pots. The median weekly returns are $113.78, as shown in Figure 12. Figure 13 shows the distribution of hourly earnings. To get some idea of the returns to labor (lobsterman), we estimated "profits" or return on investment by taking 15 percent of total business investment. Fifteen percent was considered an ade-

Table 14.—Relation of lobster production and cost to various boat characteristics and operating patterns (1967).

	Dependent variables								
Independent variable	Landings	Fuel & oil	Bait, salt, ice	Wages	Repair & maint.	Ropes, buoys, etc.	Insurance	Utilities	Depreciation
Constant	−8,658.3	−413.77	−325.68	−402.39	−159.48	−97.76	−73.53	205.56	−74.98
Boat size	233.34	10.628			5.4708		3.530		22.30
	(2.79)	(1.03)			(1.31)		(2.68)		(8.86)
Boat age	−160.80				1.2369		−4.430		−9.977
	(3.44)				(.53)		(4.79)		(5.97)
Horsepower	−11.484	1.9625			−.06030				−.1685
	(1.92)	(2.74)			(.20)				(.93)
No. traps	28.64		3.5900	4.2972	.33164	.8590	7.417		
	(13.19)		(12.59)	(7.57)	(3.06)	(3.54)	(1.68)		
No. trips	50.384	2.2374	3.6440	−.91818	.85385	4.262	.3826		
	(5.55)	(2.01)	(4.05)	(.38)	(1.89)	(4.89)	(2.48)		
Lbs. landings								.0130	
Distance trav.	203.28	13.065			2.2083			(4.65)	
	(1.96)	(1.01)			(.43)				
Sample size	186	186	186	186	186	186	186	186	186
R^2	.75	.19	.55	.31	.19	.22	.23	.11	.41
$\overline{R}^2$	.74	.16	.55	.29	.15	.21	.21	.10	.40

t-values in parentheses.

Table 15.—Revenue, costs, and returns to boat and lobsterman for a sample of 186 boats, 1967.

	Total	Average per boat	Percent of total
Income from fishing	$1,945,558	10,460	100
Lobster landings	1,890,143		
Other fishing	55,415		
Costs of fishing and returns to lobstermen and boat	1,945,558	10,460	100
Costs of fishing	825,651	4,439	42.44
Bait, salt, ice	211,068	1,135	10.86
Ropes, buoys, clothing	146,495	788	7.53
Wages to helpers	126,127	678	6.48
Fuel and oil	113,302	609	5.82
Depreciation	90,658	487	4.65
Utilities, transportation	67,277	362	3.46
Repair and maintenance	47,029	253	2.41
Insurance	12,252	66	.63
License, taxes	11,441	62	.59
Returns to boat and lobstermen (i.e., balance after subtraction of costs from total income)	1,119,907	6,021	57.56

Source: Data supplied by Dr. Andreas Holmsen of the University of Rhode Island.

quate return on capital given the riskiness of the lobster business investment. Figure 14 shows the results. The average weekly earnings were reduced to $116.79 as an estimate of the return for laboring. It is interesting to note that given the capital investment, many

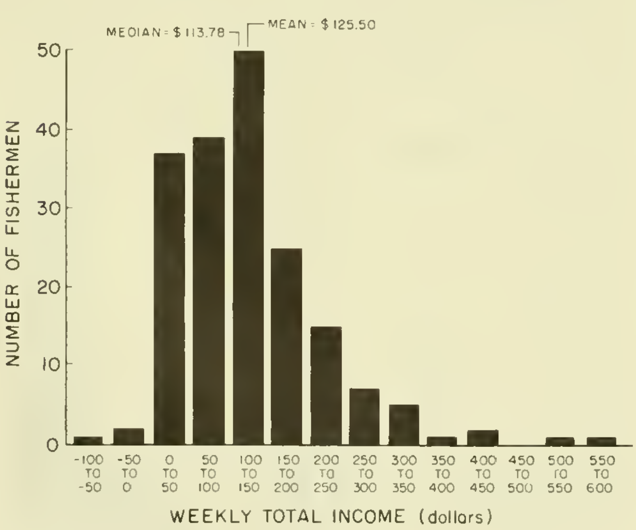


Figure 12.—Weekly total income for a sample of American lobster boats, 1967.

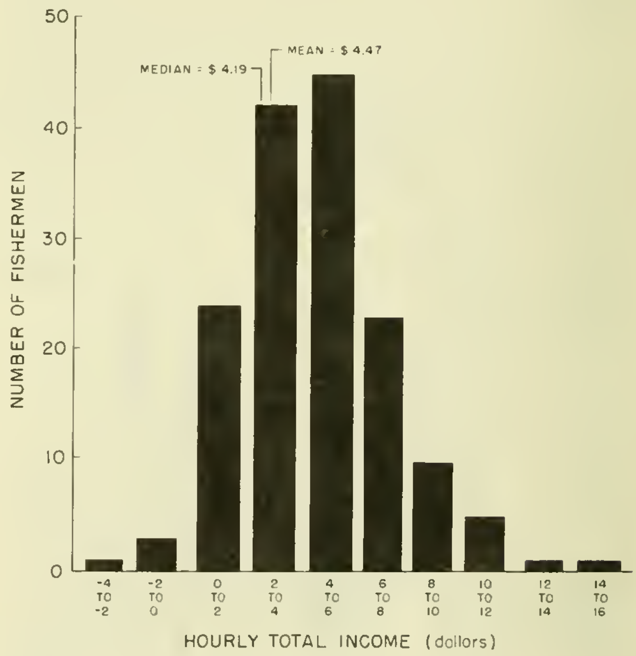


Figure 13.—Hourly income for a sample of American lobster boats, 1967.

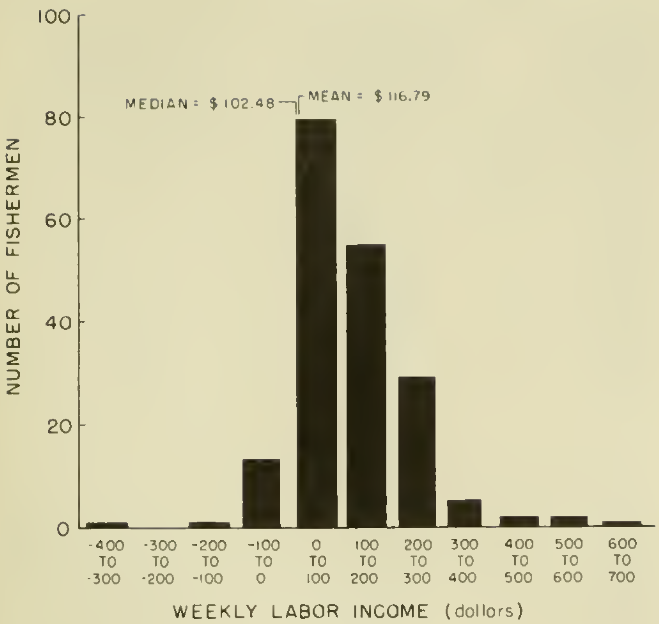


Figure 14.—Estimated labor weekly income for a sample of American lobster boats, 1967. (A 15 percent return on capital invested in boat and pots was subtracted from the total income—after expenses—to obtain weekly labor income.)

lobstermen worked for negative or no wages at all. That is, the additional laboring made a negative contribution after adjustment for capital investment. This is clearly a risky industry.

(5) Determinants of the Distribution of Returns.—Why do hourly and weekly returns to boat and lobsterman vary so greatly, as shown in Figures 12-14? To explain this variation, we related "returns" per week to the following variables:

(1) Crew size
(2) Boat size (length)
(3) Boat age
(4) Horsepower
(5) Number of traps fished
(6) Trips per week
(7) Average price received per pound of lobsters
(8) Years lobstering
(9) Average depth fished in
(10) Distance to grounds (summer).

Obviously, there are other factors which may explain the variation in returns. Managerial ability is not easily quantifiable, but the so-called "good captain" hypothesis is well recognized in the literature on cost and earnings in fishing. Table 16 shows the statistical results. Of all the variables specified above, only boat, age, number of traps fished, and trips per week were statistically significant at the 5 percent level. Finally, Figure 15 shows the actual and computed distribution of average weekly earnings. Notice that we underpredicted the very low income group (0-$100) and overpredicted the middle income group ($100-$200) while doing fairly well with the upper income group ($200-$300). The large unexplained variation in earnings may be due to many factors such as firms not incurring actual cost by doing work themselves. This is reflected in our poor ability to explain costs (Table 14). Therefore, it must be concluded that much of the variation in lobstermen's earnings are explained by "unexplained" variation in costs of production as well as the "good captain" hypothesis.

E. Supply Relationships.

Although the demand for all lobsters was considered above, for management purposes we want to focus on one component of the total supply: the inshore Maine American lobster stock. The number of traps fished in this fishery expanded from approximately 222,000 in 1940 to 1.2 million in 1971, or an annual rate of growth of 5.6 percent. This largely resulted from the rising demand pressures discussed above. Dow showed the strong relation between the catch per trap of lobsters and two important factors: (1) the total number of traps fished and (2) seawater temperature.[7] This was also demonstrated in Section III. That is, catch per trap falls as the total number of traps fished increases. However, within certain ranges, catch per trap is increased by increases in seawater temperature which causes lobsters to be more active in foraging and to grow more rapidly. Therefore, the supply of inshore Maine lobster is largely governed by the population dynamics indicated in Section III. The estimated maximum sustainable yield from the fishery was estimated to be about 22,108,000 pounds (live weight) that can be taken with approximately 642,000 traps (see Table 12). Presently, there are 1.2 million traps (1971) in the fishery catching less than 18,000,000 pounds. As indicated above, the Maine inshore fishery is considerably overcapitalized on all accounts. Therefore, it is safe to conclude that further increases in the demand for lobsters in general will result in decreases in supply from the Maine American lobster fishery.

If additional lobster supply is desired, then the most likely source is existing populations. Several studies to evaluate what effects minimum legal size increases would have on the fishery have been conducted in Maine (Baird and Harriman, 1951; Baird, 1953; Dow, Goggins, Harriman, and Hurst[8]) based on size-

[7]Dow, R., D. Harriman, G. Pontecorvo, and J. Storer. 1961. The Maine lobster fishery. Unpublished manuscript submitted to the U.S. Fish and Wildlife Service, Washington, D.C. (May be obtained from Sea and Shore Fisheries, Maine.)

[8]Dow, R. L., P. L. Goggins, D. M. Harriman, and J. W. Hurst, Jr. 1962. The lobster resource of Maine. Unpubl. ms., Dept. of Sea and Shore Fisheries, Maine.

Table 16.—Relation between returns to boat and lobstermen and various operating characteristics.

Operating characteristics	(1) Weekly returns to lobstermen and boats	(2) Hourly returns to lobstermen and boats	(3) Weekly returns to lobstermen and boats[1]	(4) Hourly returns to lobstermen and boats[1]
Constant	−192.70	−1.7807	−199.99	−1.5057
Vessel size	3.0884	.06773	3.4615	.07376
	(1.67)	(1.34)	(1.87)	(1.44)
Vessel age	−2.4547	−.06013	−2.7361	−.06838
	(2.31)	(2.05)	(2.58)	(2.32)
Horsepower	−.17969	−.00288	−.17145	−.00262
	(1.48)	(0.87)	(1.41)	(0.78)
Crew size	−3.3631	−.14136	−2.2868	−.10202
	(0.17)	(0.26)	(0.12)	(0.19)
Number of traps	.31477	.00636	.31322	.00610
	(6.30)	(4.62)	(6.29)	(4.40)
Trips per week	31.894		34.554	
	(4.63)		(5.02)	
Average price	73.889	4.0541	71.659	4.0898
	(0.58)	(1.17)	(0.56)	(1.17)
Years lobstering	−.54982	−.01218	−.45304	−.00916
	(0.79)	(0.64)	(0.65)	(0.47)
Average depth	1.2230	.02568	1.1531	.02286
	(1.14)	(0.88)	(1.08)	(0.77)
Distance in summer	3.3583	−.01569	3.4222	−.02076
	(1.43)	(0.25)	(1.46)	(.33)
R^2	.44	.24	.46	.24
$\bar{R}^2$	.39	.19	.42	.19
F	10.83	5.00	11.78	4.95
N	150	150	150	150

[1]includes depreciation
t-values in parentheses

frequency distribution, frequency of moult, and calculated growth increments. These studies indicate that growth offsets natural mortality in terms of new weight; therefore, if greater volume is desired it may be obtained by an increase in the minimum size regulation. Approximately 10 percent net volume increase for each ⅛ in. minimum carapace size increase is possible up to at least a minimum size of 3⅝ in. (discussed earlier in Section III-A).

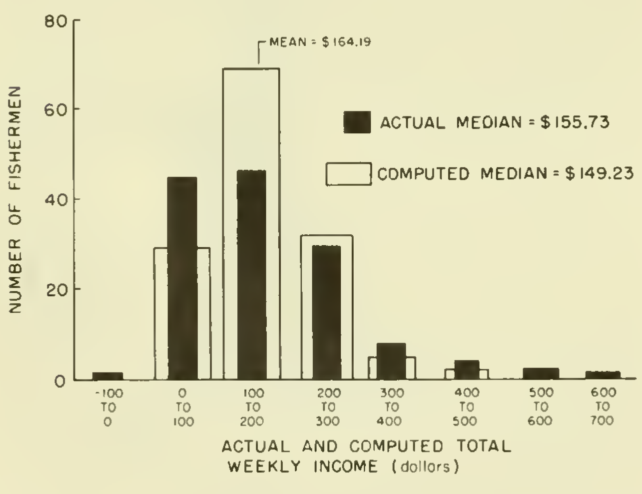


Figure 15.—Actual and computed total weekly income from a sample of American lobster boats, 1967. Weekly income includes return to fisherman and boat. (Computed from regression in Table 16.)

Measurements of the commercial catch indicate what the average carapace size and average weight will be for any given minimum size from 3¹/₁₆ in. to 3⅞ in. At 3¹/₁₆ in. average carapace size will be 3⅜ in. and average weight will be 1.1 pounds. At the other extreme of 3⅞ in. carapace average size will be 4³/₁₆ in. carapace measure and average weight will be 2.1 pounds.

Obviously, trends in abundance will have profound effect upon catch irrespective of legal size changes. Before the last minimum size change in 1958, it was predicted that the total annual catch for the next 4 yr would be: 1958, 18.3 million pounds; 1959, 20.1 million pounds; 1960, 20.9 million pounds; 1961, 21.2 million pounds. The actual catch during this period was: 1958, 21.3 million pounds; 1959, 22.3 million pounds; 1960, 24.0 million pounds; and 1961, 20.9 million pounds, or a total of 88.5 million pounds as compared with a predicted total of 80.5 million pounds.

These predictions were based on an assumed constant level of abundance derived from catch sampling between October 1949 and October 1952 when the average annual catch was 20.1 million pounds, representing 84 percent of the legal population. If predictions had been based on 1953-55 sampling, when annual catch averaged 22.2 million pounds, representing 86 percent of the legal population, then the predicted catch would have been: 1958, 20.8 million pounds; 1959, 22.8 million pounds; 1960, 23.7 million pounds; and 1961, 24.1 million pounds, or a total of 91.4 million pounds for the 4-yr period, with an error of 2.9 million pounds or 3.2 percent.

With the present minimum size, the anticipated range of lobster carapace sizes recruited by moulting from sublegal stocks is 81 mm (3$^{3}/_{16}$ in.) to 91 mm (3$^{19}/_{32}$ in.). The weight increase from 81 to 91 mm has averaged 43 percent.

An increase from 81 mm (3$^{3}/_{16}$ in.) to 83 mm (3¼ in.) would reduce the catch an estimated 9 percent in number of lobsters during the first year. During the second year the new sublegal lobsters, between 81 and 83 mm, would be expected to increase an average 14 percent in carapace length, 93 mm (3$^{31}/_{32}$ in.), and an average 47 percent in weight to 1.37 pounds, while the next $^{1}/_{16}$ in. minimum size increase would remove from the legal stock those lobsters less than 3$^{5}/_{16}$ in. in carapace length, representing 19 percent of the catch remaining between 3$^{5}/_{16}$ in. and the maximum size of 5 in. carapace. In the meantime, 3$^{3}/_{16}$ in. lobsters, representing 9 percent of the catch, during the preceding year have moulted and increased to an average carapace length of 3⅝ in. (92 mm) and an average weight of 1.34 pounds or 47 percent increase.

Since annual mortality appears to average approximately 7.5 percent per $^{2}/_{16}$ in. (3.2 mm) carapace between the minimum legal size and the maximum carapace length of lobsters recruited by moult from the sublegal population, the loss of these animals by cannibalism, predation, permanent entrapment, or other mortality causes associated with trap fishing must be subtracted from the anticipated benefit in total yield from increases in the minimum legal size. With the types of traps used in the fishery incidental mortalities will occur, at perhaps varying levels of magnitude, no matter what minimum legal size may be devised. The only means of eliminating trap-associated mortalities is to develop alternative methods of capturing lobsters.

To express number of lobsters as weight, the conversions in Table 17 have been used.

Annual sea temperature during the 3-yr period 1969-1971 has remained virtually the same: 8.9°, 8.9°, 8.7°C; yet, lobster catch has declined 8.4 percent and 3.4 percent on a year-to-year basis and 11.4 percent cumulatively (Table 18).

During the 1957-1963 period of near-optimum sea temperature, the catch of lobsters annually averaged 10.2 thousand metric tons and mean annual temperature was 8.6°C. During the equally near-optimum temperature years 1969-1971, when the average was 8.8°C the annual lobster catch averaged only 8.4 thousand metric tons, a decline of 17.7 percent. Between the two periods, average gross fishing effort increased 54 percent, from 700,000 to 1,080,000 units per year.

Table 17.—Average length-weight of lobsters.

Length		Weight	
In.	mm	Pounds	Grams
3$^{3}/_{16}$	82	0.95	432
3¼	83	1.01	457
3$^{5}/_{16}$	84	1.06	481
3⅜	86	1.12	511
3$^{7}/_{16}$	87	1.18	536
3½	89	1.25	567

Table 18.—Relation of effort, temperature, and catch, 1969-1971.

Year	Effort (millions of traps)	Annual sea temp. (°C)	Catch (pounds)	Catch (metric tons)
1969	0.81	8.9	19,834,780	8,997
1970	1.17	8.9	18,172,269	8,243
1971	1.26	8.7	17,558,351	7,964

The relationship among temperature, effort, and landings suggests that overfishing (effort) has had an annual value of nearly 6 percent in reducing catch.

Maine lobster abundance declined after 1957. Since the rate of decline has increased during the last 15 yr, it is likely, in view of the demonstrated overfishing of the resource and anticipated less favorable sea temperature conditions until the decade between the mid-1970's and the mid-1980's (H. Willett, pers. commun.), that decline during the 1973-1976 period may average about 12 percent with an annual average catch of 7,400 metric tons (Table 19).

F. Labor Force Characteristics.

The Maine Department of Sea and Shore Fisheries reports the trends in lobster licenses issued (Table 20) and the age distribution of those licensed (Table 21). However, to get some idea of the socioeconomic characteristics of the labor force, the University of Maine was given a contract by the NMFS to study this matter. The study concentrated on three typical communities rather than encompassing the entire Maine lobster fishery. These communities are: Phippsburg, Beals, and Corea (see Fig. 16). The selection was made in consultation with the Maine Department of Sea and Shore Fisheries and the National Marine Fisheries Service. The existence of some contrasts in the structure of the local economy and the relative importance of the lobster fishery in their economy weighed heavily in the selection process. Corea represents a highly specialized, isolated economy where

Table 19.—Actual Maine American lobster catch 1957,72, and estimated catch, 1973-76.

						Forecast	
Year	Catch (metric tons)[1]	Year	Catch (metric tons)[1]	Year	Catch (metric tons)[1]	Year	Catch (metric tons)[1]
1957	11.1	1962	10.0	1967	7.5	1972	7.4 (actual)
1958	9.7	1963	10.3	1968	9.3	1973	7.4
1959	10.1	1964	8.7	1969	9.0	1974	7.4
1960	10.9	1965	8.6	1970	8.2	1975	7.4
1961	9.5	1966	9.0	1971	8.0	1976	7.4
Average	10.3		9.5		8.4		7.4
% decline			−7.8%		−11.6%		−11.9%

[1]Thousands of metric tons.

lobstering is the predominant economic activity. Beals is also highly specialized but less isolated than Corea. Phippsburg's economy is more diversified and in close proximity to sources of alternative job opportunities.

Table 20.—Number of lobster licenses issued in Maine 1961-72.

Year	Number of licenses
1961	6,472
1962	5,658
1963	5,695
1964	5,803
1965	5,802
1966	5,613
1967	5,425
1968	5,489
1969	5,750
1970	6,316
1971	6,702
1972	7,117

Source: Maine Department of Sea and Shore Fisheries.

Table 21.—Age distribution of lobster fishermen 1971.

Age	Total	%
15	530	8.1
15-19	664	10.2
20-24	576	8.8
25-29	630	9.6
30-34	522	8.0
35-39	533	8.2
40-44	542	8.3
45-49	552	8.5
50-54	560	8.6
55-59	461	7.1
60-64	374	5.7
65+	588	9.0
Total	6,532	100.0

Source: Maine Department of Sea and Shore Fisheries.

Each of the areas has one feature in common: the lobster fishery is a major economic activity. It is difficult to say how representative these three communities are of the entire lobster fishery. Sufficient information is not readily available to identify the economic characteristics of the population of lobster fishermen in Maine and

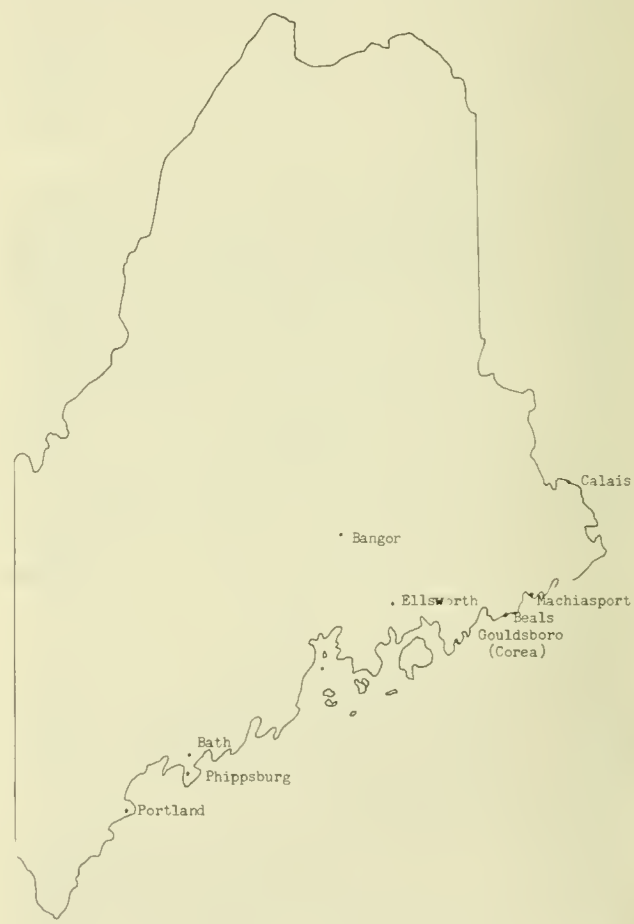


Figure 16.—Maine, selected geographic locations.

relate them to those of the sample fishermen in these communities.

To generate the information needed for this investigation, a stratified random sample of 131 fishermen was selected. The size of the sample depended essentially on the estimated cost per interview and the budgetary constraint. The allocation to each stratum was strictly according to proportion of fishermen in each community to the total number of fishermen of all three communities. The survey data were supplemented by information on the local labor market obtained through the cooperation of the regional offices of the Maine Employment Security Commission. For the survey, a structured questionnaire was developed and pretested. Using the modified questionnaire and personal interviews, the survey was completed in 6 weeks. The response rate was better than 90 percent.

There were 5,750 lobster licenses issued in the state in 1969. These 5,750 lobstermen fished a total of 805,375 traps or approximately 105.7 million trap-days during the year 1969. There have been fluctuations in the number of licenses issued over the past 10 yr. Table 20 illustrates a seemingly cyclical pattern of lobster licenses, showing a high of 6,472 in 1961, a low of 5,425 in 1967, and another high of 7,117 in 1972.

The communities chosen for study—Phippsburg, Corea, and Beals—represent 277 fishermen or 4.4 percent of the 6,316 fishermen licensed in 1970. A sample of 131 of the fishermen was randomly selected by community as shown in Table 22.

Table 22.—Distribution of the sample fishermen by communities.

Communities	Total fishermen	Sample
Beals	137	61
Corea	73	27
Phippsburg	67	44
Total	277	131

Average age of the lobstermen in the sample is 42.6 years. There are 15 below the age of 19 and 18 in the age bracket 65 and over. The median annual income for the group is $5,280 and average income is $6,213. There are 13 fishermen with income less than $1,000 and 15 with income over $14,000. Of the 118 fishermen who gave reasons for lobstering, 33 (which included 3 students) responses may be categorized as "economic" and the rest "non-economic" including home consumption, preference for the particular way of life, influence of family, and so on.

Of the 109 fishermen who supplied information on number of traps, slightly over 50 percent owned less than 300 traps; 23 fishermen owned more than 500 traps. Of the 93 fishermen who gave information on investment in trap gear approximately 50 percent had an investment of less than $2,000; only 3 had an investment of $8,000 and over. The average years of education was 9.8. Approximately 40 percent had less than 9 yr of education. Of 131 fishermen, 41 indicated that they received some type of formal vocational training in areas including carpentry, metal working, mechanic, professional, and clerical work. Of 81 fishermen when asked about preference for receiving vocational training, 63 indicated no preference. Only a small fraction expressed preference for training in electrical, professional, and carpentry work.

Among the 109 fishermen who supplied information on income from part-time jobs, 77 indicated that they had little or no income from this source. Only 7 indicated that they received more than 50 percent of their income from alternative jobs. These general characteristics of the lobster force will be used in determining the socioeconomic impact of various management schemes discussed below.

V. BIOECONOMIC SIMULATION OF THE FISHERY

A. The Nature of the Model.

Before any specific management strategies are considered, it is first necessary to understand just how a fishery functions from both the economic and biological points of view without extensive management intervention by government. This gives us a benchmark from which the economic impact of various management policies can be measured. Economic researchers first attempt to develop a bioeconomic model which will explain the most important behavioral factors for a fishery over some period of time, such as ex-vessel prices, fishing effort, earnings, and catch under conditions of free access to the fishery resource. The "model" consists of a series of mathematical relationships which hopefully approximate the economic behavior of those participating in the fishery. The predictive power of such models is greatly influenced by each of the building blocks, such as the hypothesized relation between catch and effort or catch and ex-vessel prices. The reader should remember that these models only attempt to consider the most important factors of a fishery and necessarily omit factors of lesser importance over the long run.

Although the technicalities of a bioeconomic model will not be discussed here (see Appendix A), it should be pointed out that the researcher essentially attempts to explain the determinants of the demand and supply of fish harvested from a given resource. Most of this empirical information has been developed in previous sections. Supply or catch is directly determined by the size of the fishery biomass and the number of vessels fishing the resource (discussed in Section IV-D). The number of vessels and fishermen fishing the resource is determined by the overall level of consumer demand for the fishery product (discussed in Section IV-A). Consumer demand is determined by income per capita, population, and ex-vessel prices relative to other protein substitutes. As demand expands over a period of time owing to the expansion of population and/or income, ex-vessel prices will increase, which in turn produces an increase in returns to existing vessels and fishermen. The rise in earnings induces more vessels into the fishery, thereby expanding catch given the biological limitation of the resource. The resource limitation is built into the model by relating catch to fishing effort or number of vessels fishing the resource. As fishing effort expands, the catch will eventually reach a maximum yield. Further fishing will reduce catches. Therefore, the concept of maximum sustainable yield (MSY) is the largest number of pounds of fish that can be caught on a long-run annual basis with a given level of fishing effort without impairing the viability of the stock.

The bioeconomic model does not permit overfishing the resource where the level of fishing effort is greater than that necessary to harvest MSY (which is the case for Maine American lobsters). In this case, catch will usually be less while fishermen and vessels will be more than necessary to take MSY. This situation represents a waste of capital and labor as discussed in Section III-E. The model will allow us to answer such questions as the following: What is the economic impact of a sudden increase in imports? What will happen to the fleet if the rate of growth of U.S. population slows? What is the impact of increases in per capita income of ex-vessel prices?

B. The Use of the Model.

To illustrate the usefulness of our bioeconomic simulation model for the Maine lobster fishery, we have presented in Table 23 the results of changing various critical variables or forces that influence the fishery. The initial equilibrium for the system is for 1969. Given the 1969 variables, the model predicted a catch of 22.1 million pounds (actual-19.8 million lbs.) and 848,825 traps fished (actual-805,000 traps). Now let us suppose that through economic development of Maine (through an oil refinery, etc.) the opportunity cost of labor (fishermen) increases. That is, lobstering will have to pay 25 percent better to compete with other job opportunities (such as an oil refinery) in order to keep people working in the fishery. Holding all other factors constant, this would increase the cost of lobsters (through higher wages demanded) and reduce effort in the fishery. That is, the inshore lobster fishery's product would be more expensive than competitors' products. The results of reduced effort will paradoxically be an increase in catch since the present effort exceeds that necessary to take MSY. The catch is predicted to increase to 22.3 million pounds. Similarly, an increase in exogenous supply of all lobsters through foreign imports or discovery of new domestic resources would result in a large increase in the market—25 percent—depressing prices, holding all other factors constant. The predicted result will be a contradiction in the inshore American lobster fishery due to the decline in prices. The number of traps fished would be predicted to decline to 398,424 with a catch of 17.5 million pounds. Remember, these percentage increases used for purposes of illustration would not normally take place in one year, but most probably, over several years.

Table 23.—The impact of exogenous shocks to the Maine inshore American lobster fishery on the effort, catch, and biomass.

	Vessels, full-time equivalent K^*	Traps E^*	Catch Kx^*
	Number	*Number*	*Million pounds*
(1) Initial equilibrium (1969) (computed by model)	1,508	848,825	22.1
(2) New equilibrium			
(a) Increase (25%) in opportunity cost of labor	1,213	682,524	22.3
(b) Increase (25%) in exogenous supply of lobsters	708	398,428	17.5
(c) Increase (5%) in personal per capita income	1,681	945,833	20.8
(d) Decline in water temperature by 1°	1,442	811,833	20.8
(e) Changes (a)-(d) simultaneously	685	385,789	16.4

Source: See Appendix A.

As indicated in the discussion of demand for lobsters, increases in per capita income will increase the per capita consumption of lobster on the overall level of demand. As indicated in Table 23, a 5 percent increase in per capita income will increase the number of traps fished to 945,833 for a 130 haul-day year from initial equilibrium. Unfortunately, the catch will fall to 20.8 million pounds as the fishery will become increasingly overcapitalized. Finally, seawater temperature has a positive influence on the catch within the observable range. A 1° decrease in seawater temperature will decrease supply to 20.8 million pounds and reduce the number of traps fished to 811,833. Of course, reality is much more complex where all these forces work together to provide a net influence.

VI. POLICY CONSIDERATIONS

A. Existing Regulations.

The purpose of the Maine fishery regulations is to conserve the fish, shellfish, lobsters, crabs, shrimp, and marine worms in any coastal water or flats of the

State. Regulations for the State of Maine encompass the following areas:

1. Gear or Method of Capture: Gear is restricted to pots and traps.

2. License Requirements: To fish in Maine, there is a three-year residence requirement. The annual license fee is minimal at $10 per boat per year.

3. Size Limitation: The size of the lobster is limited to not less than 3³/₁₆ in. as measured from the rear end of the eye socket to the rear end of the body shell.

4. Time Limitations: Hours of fishing are prohibited from 4:30 p.m. Eastern Daylight Savings Time, Saturday to one-half hour before sunrise of the following Monday morning from June 1 to August 31.

5. Sex Regulations: It is a violation to catch spawning lobsters or lobsters from which eggs have been removed, female lobsters with a V-notch in middle flipper or tail, or female lobster with mutilated middle flipper.

It is not the purpose of this report to evaluate the impact of these regulations on the inshore lobster fishery. However, we shall briefly review the history of lobster regulations in Maine over the 1641-1971 period.

Attitudes generated by food needs appear to have influenced the contents of the Colonial Ordinances of 1641-1647. Incidences like the following undoubtedly contributed to these attitudes (Southgate, 1853):

> In an action brought before the first general court, of the Province (Maine) in 1640, Richard Foxwell of Blue Point (Scarborough) complains of Cammock for preventing him and others from fishing for bass and lobsters in Black Point River. To this complaint Cammock answered: 'that by virtue of his Patent the Royaltie of fishing and fowling belongeth to him, and (is) not to be violently trespassed by force, and hath sustained greate damage by their fishing and cominge on his ground and otherwise'. . .

Regulation of the lobster fishery greatly influenced the extent and form of its development. The Great Pond Ordinance of 1641 (Whittlesey, 1932) furnished the foundation for all subsequent legislation and provided that:

> Every inhabitant that is an house holder shall have free fishing and fowling in any great ponds and Bayes, Coves and Rivers, so farre as the sea ebbes and flows within the presincts of the towne where they dwell, unless the freemen of the same Towne or the Generall Court have otherwise appropriated them, provided that this shall not be extended to give leave to any man to come upon others proprietie without there leave.

The first fisheries regulations established after Main became a State were designed to "protect" Maine coastal residents rather than the resources, which both Canadian and Massachusetts fishermen were apparently exploiting with more efficiency than were Maine fishermen.

The early history of conservation is primarily a history of lobster legislation of a restrictive nature. The first Maine law, passed in 1823, was a regulation prohibiting nonresidents from fishing in Maine waters without permission of local town officials. This provision closely paralleled a Massachusetts statute of 1812, the original of all lobster regulations in this country.

Between 1823 and 1872, the only lobster regulations were the acts of 1848, 1852, and 1855, which prohibited nonresidents from taking—among other species —lobsters by net, weir, seine, or other device.

Eggs and seed lobsters were first given protection by the public laws of 1872, a regulation which was repealed in 1874 by the establishment of a closed season on all lobsters from August 1 to October 15 of each year. It was further provided that any lobster less than 10½ in. in length should not be caught, preserved, sold, or exposed for sale between October 15 and the following April 1 of each year.

It was not until 1883 that any minimum size limit was placed on the canning of lobsters during the so-called open season. In addition to forbidding the canning of egg lobsters, no lobster less than 9 in. in length could be legally canned.

Changes in lobster fishing and canning restrictions were made at each legislative session during the 1870's and the 1880's (Table 24). Many of these alterations dealt with the ambiguous phraseology of existing regulations, while others broadened the scope of, and materially amended, previous statutes. In 1889 egg lobsters were again given protection.

Three forces contributed to the great emphasis placed on regulation after 1870: the decline of the coastal economy, conservation problems, and the competition between canners and the dealers engaged in the live lobster trade.

An all-year minimum size limit of 10½ in., overall length, was passed in 1895. This was the law which has

Table 24.—Summary of changes made by Maine Legislature in lobster fishery regulations.

Type of legislation	Years in which changes were made
Laws changing legal length at which lobsters could be taken	1872, 1879, 1883, 1885, 1889, 1891, 1895, 1933, 1935, 1942, 1957
Laws establishing closed seasons along the Maine Coast	1874, 1875, 1883, 1885, 1887, repeal 1895[1]
Laws prohibiting the taking of spawn lobster	1872, 1874, 1883, 1885, 1887, 1889 (continues in effect)

[1]Monhegan Island fishermen have a private and special law providing for a closed season from June 25 to January 1.
Source: Sea and Shore Fisheries, State of Maine.

been referred to as putting an end to the lobster canning industry in Maine.

The method of measuring lobsters remained unchanged until 1907 when a carapace measure of 4¾ in. from the end of the nose to the center rear of the body shell was established as the minimum legal size.

The legislature of 1903 made provision for the purchase of eggbearing lobsters by the state for conservation and propagation purposes. From 20,000 to 40,000 pounds of seeders are annually purchased for planting in Maine waters in addition to the several thousand required for the operation of the hatchery and rearing station.

The increasing importance of the industry and the need for control measures over the resource led to the establishment of licensing provisions in 1915 for lobster fishermen, dealers, and transporters. From the handful of commercial lobster fishermen operating during the middle 1800's the number had grown to 3,000 in 1915.

Under a provision of the laws of 1919, a new method of measuring lobsters was enacted. The minimum legal size was established at 3½ in. measured from the eye socket to the nearest point at the rear of the body shell.

Subsequent legislation defined in detail the method for carapace measurement, from the rear of the eye socket on a line parallel to the center line of the body shell to the rear of the body shell.

On the assumption that large lobsters constituted a more desirable breeding stock, the so-called double-gauge lobster measure became law in 1933. The minimum legal size was defined as 3¹/₁₆ in. and the maximum as 4¾ in. In 1935, the maximum legal limit was raised to 5 in. and, in 1942, the minimum legal limit was raised to 3⅛ in.

No additional changes in size regulations were made until 1957. A minimum size of 3 ³/₁₆ in. was passed by the Legislature in that year, as was a temporary maximum of 5³/₁₆ in. which reverted to 5 in. on 1 January 1960. The minimum size law of 1957 conformed to that enacted by Massachusetts and to regulations adopted for most Canadian fishing areas a few years earlier and thus provided a degree of uniformity in the regulation of the fishery.

B. Economic Impact of Some Selected Alternative Management Schemes.

We shall consider the economic impact of five alternative policies that could be adopted to manage the Maine inshore American lobster fishery. These management strategies assume that some central authority (i.e., states) could impose these regulations. Further, the following strategies are meant to be illustrative and do not exhaust all possible alternatives. Also, two other management strategies suggested by Reeves (1969) and Sinclair (1960) will be reviewed. As other management strategies are suggested by industry, government, and the academic community, the model formulated above may be used to predict their impact. The specific objectives of these management strategies will be discussed below. All strategies have two common objectives: (1) to protect the resource from overexploitation and (2) to allow maximum freedom for operators to function in a free enterprise fashion.

a. Freeze on existing (1969) fishing effort by placing a license fee on traps. Under this scheme, the regulatory authority would calculate a license fee on traps which would keep the level of fishing effort constant despite an increase in the demand for lobsters. A license fee should not be levied on the individual vessel because this would not control the number of traps fished per vessel. The increased cost of operations due to the license fee would make it uneconomical for vessels to enter the fishery even if ex-vessel prices had increased. In essence, the license fee would siphon off increased revenue (or profits) from an increase in ex-vessel prices, assuming the latter increases faster than the cost of operations. For purposes of illustration, let us assume that we desire to manage the inshore lobster fishery commencing in 1974. Given the trends in U.S. population, personal income, consumer prices, lobster imports, and other domestic production to the year 1974, it would be necessary to place an estimated annual license fee of $2.27 on each lobster trap fished in order to keep fishing effort at its 1969 level as indicated in Table 25. The regulatory authority would collect approximately $1.93 million in license fees which could be used to finance resource research, enforcement, and surveillance.

The bioeconomic model discussed above (Section V-A and Appendix A) was used to estimate the necessary license fee. It should be emphasized that these calculations are merely rough estimates and only serve to give the reader some idea of the magnitude of such taxation. The illustrative tax is also based upon an extrapolation of trends 5 yr ahead of 1969. If we did nothing, it is estimated that the catch would be lower and more fishermen and traps would be employed in the fishery by 1974. Obviously, the situation would worsen as demand for lobsters expanded and the resource became increasingly overfished.

The license fee plan does, however, have many disadvantages. First, a license fee on traps fished does not really get at the utilization rate. One might expect that a license fee on an individual trap might induce fishermen to fish each trap more intensively and thereby reduce their number of traps. At this point, we do not have any information on utilization rates whereby the license fee could be adjusted upward if utilization increased. Second, enforcement and surveillance might be difficult along the coastline from Maine to North Carolina. Third, and most important, the quantitative tools and projected figures needed to calculate a tax are at best crude and would have to be used each year for computation of the license fee.

b. Reduce the existing level of fishing effort to that

Table 25.—Projected impact of various management schemes imposed on the Maine inshore American lobster fishery.[1]

Economic variables	Estimated values before imposition of management strategies (1969)	Impact after the imposition of selected management strategies for 1974: (1) Freeze at 1969 level of fishing effort	(2) Reduce fishing effort to E_{max}	(3) Reduce fishing effort so MC=P	(4) Issue stock certificate to vessel owner while freezing effort at 1969 level	(5) Do nothing
1. Catch (mill. lbs.)	22.1	22.1	22.5	19.0	22.1	21.7
2. Value of catch (mill. $)	19.9	28.3	28.8	24.9	28.3	28.0
3. Vessels (full-time equiv.)	1,508	1,508	1,339	810	1,508	1,594
4. Traps	848,825	848,825	753,589	455,868	848,825	897,329
5. Ex-vessel price ($/lb.)	0.90	1.28	1.28	1.31	1.28	1.29
6. Total license fees collected (thou. $)	0	1,926	5,378	10,774	0	0
7. License fee per vessel ($)[2]	0	1,277	4,016	13,300	0	0
8. License fee per trap ($)	0	2.27	7.14	23.63	0	0
9. Return per vessel and fisherman ($)	6,365	8,400	8,400	8,400	11,966	8,400

[1]Projection of 1974-impact of selected management strategies. Assumes that F° = 48°; Y = $677.9 billion, (1969 prices); POP = 212.4 million; $Q_0 + 1$ = 190.4 million pounds, and $\bar{\pi}$ = $15,292. All prices and dollar values projected for 1974 are expressed in 1972 dollars.
[2]The license fee per vessel was obtained by multiplying the license fee per trap by the average number of traps (562.8) fished per full-time vessel.

necessary to harvest MSY by placing a license fee on traps. With this scheme, the regulatory authority would calculate a license fee on traps which would reduce the level of existing effort to that necessary to harvest MSY (estimated to be about 753,589) despite an increase in demand for lobsters. Because we are actually reducing fishing effort as opposed to freezing it at the 1969 level, the estimated 1974 license fee per trap must be higher, or $7.14; actual catch will not be significantly higher. The regulatory authority would receive approximately $5.38 million in license fee revenue. However, this plan has all the disadvantages of a general license fee plan discussed above.

c. Reduce the existing level of fishing effort to that necessary to make the marginal cost of landings equal to ex-vessel price.[9] The idea here is to obtain the greatest "net economic benefit" and was suggested by such economists as Crutchfield and Pontecorvo (1969). If a regulatory authority had tried this for the year 1974, it would have had a drastic impact on the fishery as the number of full-time equivalent vessels and traps would be reduced by almost 50 percent. To accomplish this objective, an estimated 1974 license fee of $23.63 per trap would be needed. This would yield the regulatory authority approximately $10.8 million in revenue.

From an economic point of view, it is argued that this management strategy will result in the most efficient operation of the fishery if fishermen and vessels can easily move to other fisheries or industries. However, this strategy may be particularly unwise in rural areas such as Maine where labor mobility is low. A drastic cutback in the number of fishermen may increase social problems where the social cost would greatly exceed any social benefits derived from such a management strategy. Therefore, this management strategy is difficult, if not impossible, to justify on economic grounds for many rural areas where the fishing industry is located and also has the same disadvantages as a general license fee plan on traps as discussed above.

d. Issue "stock certificates" to each vessel owner based on average catch over the last 5 years while freezing the existing level (1969) of fishing effort. Under this scheme, the historic rights of each fishing firm would be recognized. In a manner similar to a private land grant procedure, the regulatory authority would simply grant each fisherman a "private" share of an existing resource of catch. The stock certificate would be evidence of private ownership. Individual fishermen would be free to catch up to their allotted

[9]For most industries, output will expand in response to demand up to the point where the marginal cost of production (i.e., additional cost of producing one more unit of output) is equal to the price received in the marketplace. This is considered an efficient level of production. In the fishing industry, the condition does not hold because of the common property nature of the resource coupled with resource limitations. Marginal cost pricing is never achieved in fishing, and it is argued by some economists that regulations should be so structured to achieve this objective.

share through the use of pots or other biologically permissible technology; or, if they desired, trade their stock certificates to others for cash.

Suppose the regulatory authority were to freeze the level of fishing effort at the 1969 level and distribute the catch via a stock certificate to the existing fishermen.[10] It should be pointed out that the regulatory authority fixes effort when it selects a given catch. The selected catch could be either MSY or any other level of catch deemed by the regulatory authority not injurious to the viability of the stock. The expansion in demand for lobsters by 1974 would generate excess profits for those individual fishermen who were initially endowed with the property right. By 1974, it is estimated that a full-time lobsterman would be earning $11,966 a year of which $3,566 will be excess profits (i.e., above opportunity cost). To insure against increasingly excessive returns, fishermen holding stock certificates might be charged a fee to provide the regulatory authority with funding to conduct scientific investigations and enforcement.

It should be noted that this plan is identical to the license scheme which freezes effort at the 1969 level. However, in the latter case excess profits are taken by the regulatory authority, while for this strategy fishermen are allowed to hold onto the profits generated in the fishery. Since many fisheries are located in rural areas where earnings are traditionally low, this strategy might be justified on the basis that it will raise income levels and thereby help improve living standards to levels comparable to those prevailing in urban areas. This management strategy would, of course, be popular with those already in the fishery. However, new entrants would have to buy stock certificates from those initially in the fishery. This would pose certain questions of equity and legal precedent which are beyond the scope of this paper.

e. No management strategy. When considering the economic consequences of alternative management strategies (*a* through *d*), it is always wise to assess the results of doing nothing. This gives policy-makers a better perspective in evaluating the benefits from taking action.

The consequence of "doing nothing" would be overcapitalization by 1974 with an expansion in the number of full-time equivalent fishermen and traps fished. Over 48,000 excess traps would be in the fishery, and the catch would fall to 21.7 million pounds as computed by the model. However, we can see that this estimate is *very* conservative since there were already 1,247,000 traps in the fishery by 1972, an increase of 398,000 traps. The fishery has been and will grow increasingly overcapitalized and the resource greatly overexploited as demand increases for lobsters during the 1970's. On economic grounds, these results are hardly acceptable because more fishermen and vessels will be catching less.

f. Other suggested management strategies. Reeves (1969) proposed a hike in license fees to "eliminate" marginal or part-time fishermen. He suggested that the present $10 yearly fee in Maine be raised $10 a year over the next 9 yr to a limit of $100. In 1969, a little less than one-half of the lobster fishermen were part-time. As defined by Reeves, a part-time lobster fisherman is one who gains less than one-half of his annual income from lobstering.

The first step in most suggested limited entry schemes is usually to restrict the fishery to full-time utilization of capital and labor. Two problems occur with this policy. First, the part-time fishermen may represent the most efficient way of taking the catch. If so, the full-time fishermen may be eliminated by increased license fees. Second, license fees do not directly control fishing effort since fishermen may fish more traps. However, Reeves went on to argue strongly for limiting the number of traps each fisherman is allowed to set. It is not quite clear whether anyone knows the optimum number of traps per vessel.

Rutherford, Wilder, and Frick (1967) in their study of the Canadian inshore lobster fishery endorsed the system suggested by Sinclair. They stated:

> An alternative management system is that suggested by Sinclair (1960) for the salmon fisheries of the Pacific coast. This would use the licensing of fishermen to limit entry into the fishery. In the first stage, lasting about 5 years, licenses would be reissued at a fee but no new entries would be licensed and it would be hoped that during the period there would take place a reduction in the labor and capital input, to take the maximum sustainable catch of salmon at a considerably lower cost. After the end of the first stage, licenses would be issued by the government under competitive bidding and only in sufficient numbers to approximate the most efficient scale of effort; the more competent fishermen would be able to offer the highest bids and it would be expected that the auction would recapture for the public purse a large portion of the rent from the fisheries that would otherwise accrue to the fishing enterprises under the more efficient production conditions in the fishery.
>
> An arbitrary reduction in the number of fishermen by restriction of licenses to a specified number would entail injustice and inequity as well as grave administrative problems in determining who should be allowed to continue fishing. The auctioning of licenses to exploit a public property resource is justifiable in a private enterprise system of production,

[10]A reviewer of this paper has suggested that since the MSY could be harvested with approximately 600,000 pots, why not issue transferable licenses to existing fishermen to fish half the number of pots he is currently fishing (1,200,000 pots were fished as of 1972). This would avoid taxing existing fishermen out of the fishery. This approach is similar to the stock certificate plan which would freeze the catch (and resulting effort) at 1969 levels—close to MSY—and establish transferable property rights; however, it would pose one of the problems associated with the tax schemes. That is, with the reduced number of traps per fisherman, there may be an increase in the degree of utilization which was discussed earlier. Controlling absolute catch itself (say at MSY) automatically controls fishing effort if proper enforcement and surveillance are maintained.

particularly when the state is incurring heavy expense to administer and conserve the resource; the recovery by the state of some part of the net economic yield by means of a tax on fishermen (or on the catch) would recoup at least part of such public expenditures, or could be used to assist former fishermen (see strategies discussed above), for instance, by buying their redundant equipment. A tax on fishermen through the auctioning of licenses has, at least, the merit of using economic means instead of arbitrary regulations to achieve a desired economic objective—the limitation of fishing effort to increase the net economic yield from the fishery. Regulations have to be enforced, usually at considerable cost, but economic sanctions tend to be, if not impartial, at least impersonal and automatic in their operation (p. 99-100).

Actually, this latter management scheme is similar to the taxing scheme, but uses an auction rather than a direct tax.

C. Social Problems Created by Various Management Schemes.

Many of the schemes discussed above involve placing an additional cost of fishing on lobstermen through a license fee or auction to reduce fishing effort. If fishing effort must be reduced or held constant by license fees, some individuals will leave the fishery or be discouraged from entering. Although our general model discussed above indicates how many full-time equivalent fishermen might leave the fishery, we still do not have an adequate profile of just which group will leave.

To analyze the problem, we shall use the survey discussed above taken by a team of economists at the University of Maine in the summer of 1970. Three small communities in Maine—Phippsburg, Corea, and Beals—were samples. One hundred and thirty one fishermen were interviewed, so that the sample represented 2.2% of the fishermen population. The sample appears to be fairly representative in terms of age composition and other demographic features. In addition, it reflects the appropriate proportion of full-time to part-time fishermen found in the population of 6,316 fishermen.

The types of questions asked were designed to obtain the following type of information (see Section IV-F for discussion of socioeconomic characteristics).

Categories	*Types of Information*
Demographic	Age Family size and composition Mobility Marital status
Socioeconomic	Income Employment history Education and training Monetary return Parental occupation Housing
Operational	Gear types Investment in boat and gear Operating expenses Maintenance and repair expenditures Size of operations Seasonal patterns Rate of capacity utilization
Behavioral-Attitudinal	Reasons for lobstering Job interests Attitudes toward leaving the lobster industry Job-seeking Attitudes toward training, views on excess capacity

Given all of the information obtained in the survey, the sample was divided into four groups based upon the degree of mobility out of the fishery. Group *one* includes the potentially employable individuals who possess skills which are marketable in the local labor market.[11] This group also includes all part-time fishermen in the sample. Group *two* consists of the possibly trainable fishermen. The criterion established for this group is twofold: 1) individuals have to be less than 35 yr old and 2) they must have enough education so that they can participate in and benefit from training programs. Despite possible subjectivity involved in the selection criteria, group two can serve as an approximation of the intermediate individuals who are neither completely mobile nor completely immobile. Group *three* consists of potential hardcore unemployed fishermen. These are the individuals who are between 35 and 65 yr old and who have no marketable skills. Finally, group *four* contains those individuals who are not in the labor force—students or fishermen over 65.

The procedure was to derive some estimates of opportunity cost for the sample fishermen.[12] For groups three and four, opportunity costs were assumed to be extremely low. For groups one and two, estimates of regional wage rates for the particular skills indicated were obtained via the Maine Employment Security Commission. Ignoring capital costs, we can derive total social cost by adding our estimates of opportunity cost to variable expenses, calculated from answers given in the survey. Since gross income was also obtained from the survey, we can determine average social cost per unit of output (AC) for each fisherman in the following manner:

[11]The Maine Employment Security Commission provided supplemental information which was useful in ascertaining which skills were marketable in the areas covered by the survey.

[12]Returns necessary to make it profitable for vessels and fishermen to fish for lobsters.

$$AC = \left(\frac{\text{Opportunity Cost + Variable Expenses}}{\text{(Gross Income)}} \right) \times \text{(Price)}$$

The price used was $0.80, the average annual price per pound of Maine lobsters in 1970.[13]

Figure 17 plots average social cost against the ranking of fishermen on this basis. This ordinal ranking can also be translated into a cardinal measure if, for example, we wish to ascertain how many individuals from the sample will leave the fishery if the effective price is reduced by a given amount.

To determine which of the groups comprise high and low average social cost, we have derived the following percentage breakdowns. Each percentage given relates to a given group in a particular quartile.

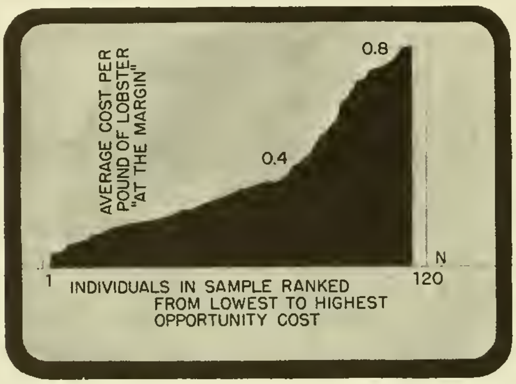


Figure 17.—Ranking of individuals in sample of lobstermen according to opportunity cost.

Group 1	*Group 2*	*Group 3*	*Group 4*
In the lowest 25% average cost rankings (34 members) there are:			
2/54= 3.7%	6/16= 37.5%	12/29= 41.4%	14/36= 38.9%
In the next lowest 25% (33 members):			
12/54= 22.2%	3/16= 18.8%	9/29= 31.0%	9/36= 25%
In the next lowest 25% (33 members):			
14/54= 25.9%	2/16= 12.5%	6/29= 20.7%	11/36= 30.6%
In the highest 25% (35 members):			
26/54= 48.1%	5/16= 31.25%	2/29= 6.9%	2/36= 5.6%
Total:			
100.0%	100.0%	100.0%	100.0%

[13]The equation used to compute AC could have been obtained by merely dividing the numerator of the first term by quantity assuming price received by fishermen (in the sample) is approximately the same as the average annual ex-vessel price per pound of lobster for Maine in 1970. A check of our sample revealed unsignificant price deviation for individual fishermen from the annual average, indicating that the market was fairly competitive and uniform.

It is clear that a disproportionately higher number of fishermen in group one and group two would leave the fishery in response to a limited entry scheme such as a license fee measure, auctioning device, etc. Therefore, it may be concluded that any management employing a license fee would probably result in those leaving the fishery that have the greatest mobility. *Unemployment would be minimal since the highly mobile group would leave.* However, the immobile group would be forced to absorb the tax themselves, thereby lowering their income.

Let us look at an example of how we can determine the socioeconomic impact of a management scheme that involves a tax. Suppose a license fee on traps (see management strategies discussed above) that *reduced* the average returns to the fisherman by $0.32 per pound. This would reduce the revenue per pound from $0.80 to $0.48 per pound. Using our sample, 35 individuals would leave the lobster fishery because they would not be able to make their opportunity cost (i.e., they could make more in other industries). This group would have the following characteristics:

1st Group to Leave	Average Age	Education	Days Lobstering
	39.8	11.06	106.1

Who would be the last to leave the lobster fishery? Those individuals (lowest 35 in sample) have the following characteristics:

Last to Leave	Average Age	Education	Days Lobstering
	48.5	9.56	86.3

As anticipated, the socioeconomic consequences of imposing a license fee on gear, other forms of license fees, or auctioning the right to fish would be to cause the individuals with the following characteristics to leave the fishery:

1. *Younger lobstermen;*
2. *More educated lobstermen;*
3. *Lobstermen tending to spend more time in the fishery.*

This group (i.e., first to leave) is pretty much as expected; however, it does indicate that lobstermen spending more time in the fishery (than the hardcore group—106.1 days) would leave first.

Therefore, we have concluded the following concerning the socioeconomic impact of the various management schemes discussed above:

(1) License fee levels that would actually displace labor (i.e., reduction in fishing effort) would have a

minimum unemployment impact since the group that would leave is relatively mobile;

(2) License fee schemes would considerably reduce income of those remaining in the fishery, which would be a disadvantage to this proposal;

(3) A reduction in the degree of capitalization through any of the management plans would probably raise total revenue produced in the fishery with an increased catch which would benefit the entire fishing community;

(4) From a social point of view, the stock certificate plan has the least disadvantages from the standpoint of the fishing industry and surrounding communities.

VII. CONCLUSIONS

Biology.

(1) The American lobster ranges from Labrator and Newfoundland to the Carolinas with the greatest commercial concentration along the Maine and Nova Scotian coasts;

(2) The greater the concentration of hiding places the greater appears to be the concentration of the American lobster population;

(3) American lobsters are scavengers, and will eat any *dead* flesh available but may supplement their diet with live mollusks, marine algae, and microscopic plants;

(4) The American lobster is a sedentary animal and, therefore, is nonmigratory wherever rocky bottom provides adequte shelter and food;

(5) Counts made in Maine indicate that female lobsters produce from 6,000-40,000 or more eggs (Taylor, 1950);

(6) The lobster is a comparatively slow growing animal and is believed to be long-lived;

(7) In Maine waters, the majority of the American lobsters reach minimum legal size when they are 5-7 yr old before most females reach maturity (Krouse, 1972);

(8) Moulting of lobsters is caused when the lobster's body becomes too large for his shell;

(9) Natural and fishing mortality rate amounts to approximately 90 percent or more of the legal supply;

(10) Natural mortality is estimated to be 28 to 36 percent for the prerecruit class of lobsters;

(11) The recognized killers of lobsters are: (a) predation by fish, (b) cannibalism, (c) starvation, (d) disease, and (e) predation by man. The most virulent disease is caused by the bacterium *Gaffkya homari;*

(12) Of the heavy metals, copper causes the highest rate of mortality among lobsters. More acutely toxic are many pesticides and some oil fractions.

Population Dynamics.

(1) Due to fishing intensity, nearly all of the available legal population is being caught each year;

(2) The relation between catch and fishing effort reveals a maximum sustainable yield from the Maine fishery of approximately 22.1 million pounds which requires 642,000 pots hauled 130 times during the year. The actual number of pots fished in 1971 was 1.2 million;

(3) Seawater temperature has a measurable influence (within certain ranges) from year to year on the abundance of American lobsters;

(4) Using a dynamic pool model approach, present fishing mortality is well in excess to harvest the maximum yield per recruit;

(5) It is quite apparent that the Maine American lobster resource is becoming increasingly overcapitalized.

Consumer Demand for Lobsters.

(1) Over the 1950-69 period, the rate of growth in per capita consumption of all lobsters was approximately 2.4 percent per year. The rapid growth in the consumption of lobsters produced a rise in the exvessel price of 4.8 percent per year which exceeded the growth in all consumer prices, which averaged 1.7 percent per year. This factor has contributed to the rapid buildup in fishing effort in the fishery.

(2) Statistical analysis revealed that over the 1950-69 period, a 1 percent increase in per capita income produced an increase in per capita lobster consumption of 1.7 percent. However, a 1 percent increase in lobster prices (related to other consumer prices) would only reduce per capita consumption by 0.3 percent.

(3) Household consumption of lobsters constitutes about 40 percent of the total consumption and is mainly concentrated in New England and the Middle and South Atlantic areas. Institutions (restaurants, etc.) sell the main percentage of the lobster supply (domestic plus imports) throughout the United States.

Earnings of Lobster Boats.

(1) For individual boats, the number of traps fished and fishing trips is the most significant determinant of annual lobster production. Boat size, age, and distance to the grounds also influence annual production.

(2) A 1967 sample of lobster boats indicated that average weekly earnings (after deduction for returns to investment in boats and traps) of lobstermen were $116.79 per week compared with $93.07 in manufacturing industries in the State of Maine. In contrast to other industries, the dispersion in weekly earnings ranged from a loss of $400 to a positive return of $700 per week for laboring efforts.

Demographic Characteristics.

(1) Using a sample of lobstermen, it was found that the average years of education was 9.8.

(2) The average age of the sampled lobstermen was 42.6 years.

(3) Only about one-third of the sampled lobstermen had received any formal vocational training in other fields.

Management Schemes.

(1) Given the problem of overcapitalization in the Maine American lobster fishery, it is becoming increasingly apparent that management strategies must be employed (a) to protect the resource from further overexploitation and (b) to allow maximum freedom for operators to function in a free enterprise fashion.

(2) With the aid of a bioeconomic simulation model, we were able to project the impact on the resource and industry of variously proposed management strategies to central fishing effort. For example, a freeze on the level of fishing effort existing in 1969 would require a trap license fee of $2.27. An attempt to reduce fishing effort to that necessary to harvest MSY would require a license fee of $7.14 per trap. Serious disadvantages of the license fee scheme on traps are (a) difficulty in controlling utilization of the individual trap, (b) problem with enforcement, and (c) possibly a reduction in income for those that have low opportunity cost and will remain in the fishery after the imposition of the license fees on traps.

(3) A stock certificate plan to change the common property nature of the resource to a private property one by distributing the existing catch on the basis of individual historical catch offers promise of increasing incomes in the industry and overcoming many of the shortcomings of higher license fees. However, the most serious disadvantage is that the regulatory authority would not have revenues to conduct scientific investigation or provide enforcement.

(4) On the basis of our socioeconomic sample of lobster fishermen, we conclude that the license fee level that might displace labor would have a minimum unemployment impact. A reduction in the degree of capitalization will raise overall income for the fishing communities of Maine.

VIII. LITERATURE CITED

ANONYMOUS.
1957. Six-year investigation shows only random lobster movement. Maine Coast Fisherman 11(11):7.

BAIRD, F. T., JR.
1953. Probable effects of a size change upon the lobster industry. Maine Dep. Sea Shore Fish. Fish. Circ. No. 9.

BAIRD, F. T., JR., and D. M. HARRIMAN.
1951. Possible effects of legal size change upon the lobster industry. Maine Dep. Sea Shore Fish. Rep.

BELL, F. W.
1972. Technological externalities and common property resources: an empirical study of the U.S. northern lobster fishery. J. Polit. Econ. 80:148-158.

BELL, F. W., E. W. CARLSON, and F. V. WAUGH.
1973. Production from the sea. *In* A. A. Sokoloski (editor), Ocean fishery management: Discussions and research, p. 72-91. U.S. Dep. Commer., NOAA Tech. Rep. NMFS CIRC-371.

BELL, F. W., and R. F. FULLENBAUM.
1972. The Regional Impact of Resource Management. File Manuscript No. 117, Economic Research Division, National Marine Fisheries Service. [Unpubl. manuscr.].

CARLSON, E. W.
1970. Recent developments in the economic theory of commercial fisheries management—a critical evaluation. Mar. Technol. Soc., Proc. 6th Annu. Conf., p. 657-669.

CRUTCHFIELD, J. A., and G. PONTECORVO.
1969. Pacific salmon fisheries: A study of irrational conservation. Johns Hopkins Press, Baltimore, Md., 220 p.

CUSHING, D. H.
1968. Fisheries biology: a study in population dynamics. Univ. Wis. Press, Madison, 200 p.

DONAHUE, J. K.
1954. Studies on ecdysis in the American lobster *(Homarus americanus)*. 3. A method for differentiating stages of the intermoult cycle. Maine Dep. Sea Shore Fish., Res. Bull. 20, 4 p.

DOW, R. L.
1966. The use of biological, environmental and economic data to predict supply and to manage a selected marine resource. Am. Biol. Teach. 28:26-30.
1972. Pesticide spray poisoning tabbed as major lobster mortality cause. Natl. Fisherman 52(9):10C-11C.

FULLENBAUM, R. F., E. W. CARLSON, and F. W. BELL.
1971. Economics of production from natural resources: comment. Am. Econ. Rev. 61:483-487.

HARRIMAN, D.
1957. Monhegan fisherman-biologist cooperation proved effective. Maine Coast Fisherman 11(11):7,10.

HARRIMAN, D. M.
1954. The gas disease in lobsters. Maine Dep. Sea Shore Fish. Rep.

KROUSE, J. S.
1972. Size at first sexual maturity for male and female lobsters found along the Maine coast. Lobster Informational Leaflet #2, Maine Dep. Sea Shore Fish.
1973. Maturity, sex ratio and size composition of the natural population of American lobster, *Homarus americanus*, along the Maine coast. Fish. Bull., U.S. 71:165-173.

LOTKA, A. J.
1956. Elements of mathematical biology. Dover Publ., N.Y., 465 p.

PELLA, J. J., and P. K. TOMLINSON.
1969. A generalized stock production model. [In Engl. and Span.] Inter-Am. Trop. Tuna Comm., Bull. 13:421-496.

REEVES, J.
1969. The lobster industry: Its operation, financing, and economics. Master's dissertation, Stonier Grad. Sch. Banking. Rutgers Univ., New Brunswick, N.J., 170 p.

RUTHERFORD, J. B., D. G. WILDER, and H. C. FRICK.
1967. An economic appraisal of the Canadian lobster fishery. Fish. Res. Board Can., Bull. 157, 126 p.

SCHAEFER, M. B.
1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Inter-Am. Trop. Tuna Comm., Bull. 1:25-56.

SINCLAIR, S.
1960. License limitation—British Columbia: A method of economic fisheries management. Chapter III, p. 98. Can. Dep. Fish. 256 p.

SOUTHGATE, W. S.
1853. The History of Scarborough from 1633 to 1783. 1853- Maine Historical Society, Portland. 14 p.

TAYLOR, C. C.
1949. The Schoodic lobster planting experiments, supplement I. Maine Dep. Sea Shore Fish., Fish. Circ. 5, 10 p.
1950. A review of lobster rearing in Maine. Maine Dep. Sea Shore Fish., Res. Bull. 5.

TAYLOR, C. C., and F. T. BAIRD, JR.
1948. The Schoodic lobster planting experiments. Maine Dep. Sea Shore Fish., Fish. Circ. 2, 5 p.

THOMAS, J. C.
1973. An analysis of the commercial lobster *(Homarus americanus)* fishery along the coast of Maine, August 1966 through December 1970. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-667, 57 p.

WHITTLESEY, J. J.
1932. Law of the seashore, tidewaters and great ponds in Massachusetts and Maine. Boston, p. XXXVI.

WILDER, D. G.
1957. Researchers tag 100,000 lobsters during 25-year migration study. Maine Coast Fisherman 11(11):7, 24.

WORCESTER, D. A., JR.
1969. Pecuniary and technological externality, factor rents, and social costs. Am. Econ. Rev. 59:873-885.

Appendix A.—Technical Description of Bioeconomic Model

SPECIFICATION OF THE GENERAL RESOURCE USE MODEL

Before we are able to evaluate the economic impact of various management strategies, it is necessary to develop a general bioeconomic model of how a fishery functions. The following general model has been developed by Fullenbaum, Carlson, and Bell (1971):

$$\dot{X} = f(X, Kx) \qquad (1)$$

$$Kx = Kg(X,K) \qquad (2)$$

or $x = g(X,K)$

$$C = K\bar{\pi} \qquad (3)$$

$$\pi = pKx - C = pKg(X,K) - K\bar{\pi} \qquad (4)$$

$$\dot{K} = \delta_1 \pi,\ \pi>0 \qquad (5)$$

$$\delta_2 \pi,\ \pi<0$$

In the above system, X is the biomass; K equals the number of homogeneous operating units or vessels; x is the catch rate per vessel; C is total industry cost (in constant dollars) or total annual cost per vessel multiplied by the number of vessels; $\bar{\pi}$ is equal to total annual cost per vessel (in constant dollars) or opportunity cost[14]; π is industry profit in excess of opportunity cost, p is the real ex-vessel price; and δ_1, δ_2 represent the rates of entry and exit of vessels, respectively.

Equation (1) represents the biological growth function in which the natural yield or net change in the biomass ($\dot{X}$) is dependent upon the size of the biomass, X, and the harvest rate, Kx. X reflects the influence of environmental factors such as available space or food, which constrain the growth in the biomass as the latter increases. The harvest rate or annual catch, Kx, summarizes all growth factors induced by fishing activity. Equation (2) presents the industry and firm production function for which it is normally assumed that—

$$\frac{\delta g}{\delta x} \equiv g_1 > 0 \text{ and } \frac{\delta g}{\delta K} \equiv g_2 < 0.$$ [15]

In other words, catch per vessel increases when the biomass increases and declines when the number of vessels increases. Equations (3) and (4) are the industry total cost and total profit function, respectively. Equation (5) is very important since it indicates that vessels will enter the industry when excess industrial profits are greater than zero (i.e., greater than that rate of return necessary to hold vessels in the fishery, or the opportunity cost) and will leave the fishery when excess industrial profits are less than zero (i.e., below opportunity cost).

[14]Opportunity cost is defined as the necessary payment to fishermen and owners of capital to keep them employed in the industry or fishery compared to alternative employment or uses of capital.

[15]In some developing fisheries, it is possible that $g_2 > 0$. For example, in the Japanese Pacific tuna fishery, intercommunication between vessels may increase the catch rate as more vessels enter the fishing grounds.

The equilibrium condition for the industry ($\pi = 0$) may be formulated as shown below:

$$p = \frac{\bar{\pi}}{g(X,K)} \qquad (6)$$

Equation (6) merely stipulates that ex-vessel price is equal to average cost per pound of fish landed (i.e., no excess profits).

There are two important properties of the system outlined in equations (1) to (5). First, the optimum size of the firm is given and may be indexed by $\bar{\pi}$. Thus, the firm is predefined as a bundle of inputs.[16] Secondly, the long-run catch rate per vessel per unit of time is beyond the individual firm's control.[17] It is, in effect, determined by stock or technological externalities.[18] Finally, we are assuming that the number of homogeneous vessels is a good proxy for fishing effort. Alternatively, we may employ fishing effort directly in our system by determining the number of units of fishing effort applied to the resource per vessel. This will be discussed below.

A QUADRATIC EXAMPLE OF THE RESOURCE USE MODEL

By combining the more traditional theories depicting the dynamics of a living marine resource, with some commonly used economic relations, we may derive a quadratic example of the general model specified above. This example effectively abstracts from complications such as ecological interdependence and age-distribution-dependent growth of the biomass on the biological side and, furthermore, assumes the absence of crowding externalities (i.e., $g_2 \equiv 0$) in the production function on the economic side.

The dynamics of a fish stock may be depicted by the logistic growth function (Lotka, 1956):

$$X(t) = \frac{L}{1 + Ce^{-KLt}} \text{ where } L>0, C>0, k>0, \qquad (7)$$

where L and k are assumed to be environmental constants. Differentiating (7) and substituting we obtain,

[16]In other words, because we are dealing with a long-run theory of the industry, we are assuming that variations in output result from the entry or exit of optimum sized homogeneous vessels.

[17]We have implicitly assumed that such short-run changes as longer fishing seasons, etc., are all subsumed in a long-run context. Normally longer fishing seasons, for example, do not change catch rates per unit of time fished; nor do they change costs per unit of time fished. They do, however, change the effective level of K.

[18]A technological externality exists when the input into the productive process of one firm affects the output of another firm. In the context of fishing, an additional firm or vessel entering the fishery will utilize the biomass (as an input) and, as a result, in the long run will reduce the level of output for other vessels in the fleet. (See Worcester, 1969.)

$$\dot{X} \equiv \frac{dX}{dt} = kLX - kX^2 \equiv aX - bX^2 \qquad (8)$$

where $a = kL$, $b = k$.

If (8) is set equal to zero, we may solve for the nonzero steady state biomass, a/b (i.e., L). Alternatively, the limit of $X(t)$ as $t \to \infty$ yields identical results. The maximum of (8) occurs when X is equal to $a/2b$. Thus

$$\max \frac{dX}{dt} = a^2/4b. \qquad (9)$$

The introduction of fishing (i.e., harvest or Kx) is assumed to have no interactive effects, so that the instantaneous growth rate is reduced by the amount harvested:

$$\frac{dX}{dt} = aX - bX^2 - Kx. \qquad (10)$$

The economic component of the model requires the exact specification of an industry production function and an industry revenue relationship. One hypothesis regarding the fish catch is that the proportion of the biomass caught is a direct function of the number of vessels (or equivalent fishing effort) exploiting a given ground.[19] Thus, the total harvest rate is given as,

$$Kx = rKX \qquad (11)$$

where r is a technological parameter. Finally, the total revenue function for the industry may take the following form:

$$pKx = (\alpha - \beta kx)Kx. \qquad (12)$$

Equation (12) merely stipulates that the total revenue is a quadratic function of total landings, Kx. Dividing through by Kx will give us the familiar demand function where ex-vessel price is inversely related to landings, holding all other factors constant.[20] With total costs equal to $K\pi$, the profit function becomes

$$\pi = (\alpha - \beta Kx) \quad Kx - K\tilde{\pi}. \qquad (13)$$

Given these formulations the system in (10)-(13) can be reduced to two steady state functions. The first, which condenses all relevant biotechnological factors, is the ecological equilibrium equation. It plots the relationship between the biomass and the number of vessels (or fishing effort) needed to harvest the yield such that the biomass is in equilibrium. We can derive this equation by setting $\dot{X}$ equal to zero, substituting (11) into (10), and solving for K in terms of X:

$$K = \frac{1}{r}(a - bX). \qquad (14)$$

Similarly, the second equilibrium function plots the relationship between X and K under a zero profit state, i.e., under conditions that $\dot{K} = 0$, or that there is no entry to or exit from the fishery. Thus, by setting (13) equal to zero and substituting (11) into (13), we obtain,

$$K = \frac{\alpha}{\beta rX} - \frac{\tilde{\pi}}{\beta r^2 X^2}. \qquad (15)$$

These two curves are plotted in Figure 18. Their intersection at (X^*, K^*) denotes bioeconomic equilibrium. The direction of the arrows describe the qualitative dynamic changes of a point in phase space. Figure 18 represents the general case of exploitation. When (15) is combined with (14), however, we can simulate either non-exploitation (Fig. 19) or extinction as a possible dynamic result (Fig. 20). The state of the fishery—exploited, unexploited, or extinct—depends upon the parameters a, b, r, β, $\tilde{\pi}$, and α and their interrelationships. This completes our general model of how a fishery functions. Now let us turn to a specific application of the model.

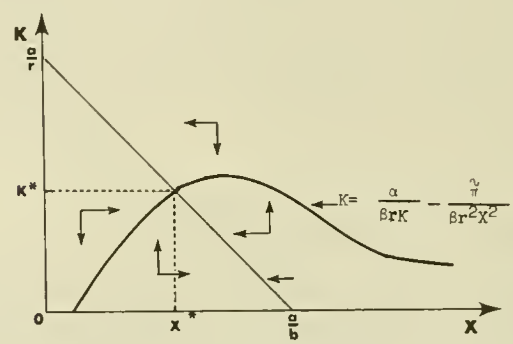


Figure 18.—Exploitation.

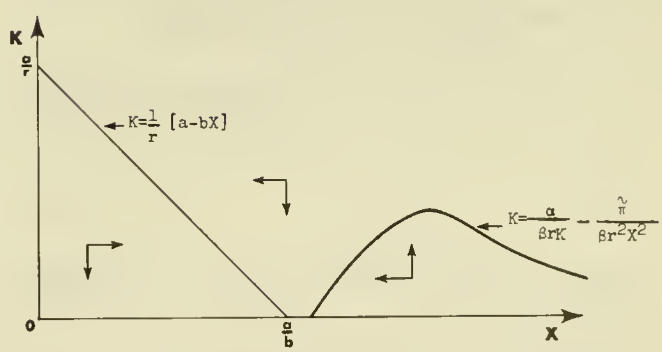


Figure 19.—Non-exploitation.

[19]Alternatively, one could assume that the proportion of the biomass caught declines as the number of vessels increases: $Kx = [1-(1-t)^k]X$, $0<t<1$. With this specification, t represents the proportion of the biomass taken by each succeeding vessel of the remaining biomass. This form was first developed by Carlson (1970).

[20]Such complicating factors as per capita income and its influence on ex-vessel prices can be introduced later as changes in the parameter, α.

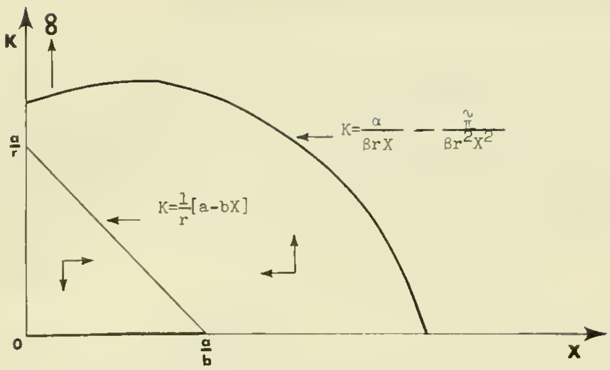


Figure 20.—Extinction.

AN EMPIRICAL CASE STUDY: THE U.S. INSHORE AMERICAN LOBSTER FISHERY

The U.S. inshore American lobster fishery —principally located off the coast of Maine —represents a good case study for a number of reasons. First, the American lobster is considered a high quality seafood item and is a popularly consumed species for which demand has been increasing rapidly (Bell, 1972). Second, because of intensive fishing pressure the resource has shown signs of overexploitation. Third, the inshore lobster fishery is one of the few grounds for which enough data are available so that some rough measures of needed biological and economic parameters can be derived. Our discussion will be subdivided on the basis of production- and demand-related estimates.

A. The Production Function and the Supply of American Lobsters.

There are four parameters on the supply side for which initial estimates are required: a, b, r, and $\tilde{\pi}$.[21] The first three can be developed by combining statistical estimation and independently derived data. Assume that the biomass is instantaneously in equilibrium (i.e., $\frac{dX}{dt} = 0$). Then, taking the inverse of (14) and substituting it for X in (11), we obtain:

$$Kx = cK - dK^2 \tag{16}$$

where $c = \frac{ar}{b}$, $d = \frac{r^2}{b}$

and

$$x = c - dK \tag{17}$$

Equation (16) is the familiar parabolic yield function postulated by Schaefer (1954). Notice that both the harvest rate, Kx, and output per vessel, x, may be specified solely in terms of the number of vessels or fishing effort. Similarly, the common property resource externality, as given in (17), is a function only of the level of K. Over a longer period of time the basic assumption underlying equations (16) and (17) may reflect a valid representation; i.e., effort or K is the only instrumental variable affecting output. There are three different parameters embedded in estimates of c and d. The only way that a, b, and r can be derived is if some independent biological information is given. More specifically, suppose that we have an estimate of the biomass consistent with maximum sustainable yield, call it $\hat{X}^0$. Since $\hat{X}^0$ is equal to $a/2b$, it follows that the following parameters may be estimated (designated by ˆ):

$$\hat{r} = \hat{d}/2\hat{X}^{\circ}, \tag{18}$$

$$\hat{b} = [\hat{d}/\hat{r}^2]^{-1}, \tag{19}$$

$$\hat{a} = \hat{c}\,\hat{b}/\hat{r}. \tag{20}$$

Thus, (17) will be estimated subject to one modification concerning the introduction of an environmental variable. Several biologists, including Dow et al. (see footnote 8), have argued that a long-term trend of declining seawater temperature is partially responsible for the decline in U.S. coastal catches.[22] It will be assumed in this study that seawater temperature (°F) affects the a term in the growth function so that,

$$\frac{dX}{dt} = a(°F)\,X - bX^2, \tag{21}$$

where °F is equal to the mean annual seawater temperature, in degrees Fahrenheit Boothbay Harbor, Maine, with $\delta a/\delta °F \equiv a' > 0$. Seawater temperature can easily be incorporated into (17) in the following way:

$$x = c' - dK + Z(°F), \tag{22}$$

where z represents the change in output per boat as a result of a one-degree change in water temperature.[23]

Data on the number of traps fished per year for the entire inshore American lobster fishery are available for the 1950-1969 period.[24] Output per trap was regressed against the number of traps and seawater

[21] An alternative approach suggested by Thomas (1973) uses the Beverton-Holt model in developing a yield/recruit relationship. However, because a stock-recruitment equation is not specified, it cannot be incorporated into our bioeconomic model at this time.

[22] Higher seawater temperature can affect the natural yield of lobsters by providing a climate in which 'molting' is facilitated. A larger number of molts will tend, *ceteris paribus*, to increase the yield associated with any given level of the biomass.

[23] Implicit in the way the effect of seawater temperature is measured is the relationship: $c = c' + z(°F)$.

[24] Unfortunately, there is no precise measure of fishing effort, for the inshore lobster fishery. The traps fished series is not adjusted for days fished or extent of utilization. Dow has used the traps fished series as a rough proxy for fishing effort.

temperature.[25] The regression estimates yielded the following results:

$$x = -31.2094 - .000039\,61T + 1.89392\,(°F) \quad (23)$$
$$(10.23) \qquad (4.63)$$

$R^2 = 0.82$

D-W = 1.023

where $T = 562.8$ (K), $\hat{d} = 12.5468$, $\hat{c} = -31.2094$. In (23), T is equal to the number of traps fished per year and t-ratios are in parentheses. Both T and °F are statistically significant at the 5 percent level and exhibit the correct sign; the Durbin-Watson statistic indicates no significant autocorrelation.

The only step required to obtain the biotechnological parameters is an estimate of the biomass ($\hat{X}_0$) consistent with maximum sustainable yield. It has been calculated that (assuming a temperature of 48°F) the fishable stock of Maine inshore lobster consistent with maximum sustainable yield is equal to 21.8 million pounds.

Finally, on the basis of recent cost studies, we have derived an estimate of $\bar{\pi}$ for 1966 equal to \$12,070.[26] Therefore, on the supply side, the estimated parameters for 1969 are the following:

$\hat{a} = 2.06832$,
$\hat{b} = 4.75476 \times 10^{-8}$,
$\hat{r} = 7.72379 \times 10^{-4}$,
$\hat{\bar{\pi}} =$ \$13,191 (see footnote 26).

B. The Demand Function for American Lobsters.

Only knowledge of $\hat{\alpha}$ and $\hat{\beta}$ is needed in order to complete the empirical component of the study. The estimation procedure is rather straightforward. We may specify the following demand function for *all* lobsters:

$$\frac{C}{N} = F - m(P'/\mathrm{CPI}) + g(Y/N), \quad (24)$$

where C is equal to consumption of all lobsters, P' is the money ex-vessel price of American lobsters, Y is aggregate U.S. personal income (1967 prices), N is U.S. population, and CPI is the consumer price index. Since there are no exports of lobster, the following identity holds:

$$C = I + Q_0 + Q_{in} \quad (25)$$

where I, Q_0, and Q_{in} are the level of imported lobsters, U.S. production of all other lobsters, and U.S. production of inshore northern lobsters, respectively. Given (25), equation (24) may be solved in terms of P, or,

$$P = \frac{P'}{\mathrm{CPI}} = \left[\frac{F}{e} - \frac{1}{mN}(Q_{in} + Q_0 + I) + \frac{gY}{mN}\right]. \quad (26)$$

If Q_0, I, Y, CPI, and N are held constant, equation (26) gives a unique relationship between the ex-vessel price of American lobsters and quantity landed.

Using data over the 1950-1969 period, the parameters of equation (24) were estimated using least-squares:

$$\frac{C}{N} = -.0632 - .005029\left(\frac{P'}{\mathrm{CPI}}\right) + .00051\left(\frac{Y}{N}\right) \quad (27)$$
$$(2.06) \qquad (5.38)$$

$R^2 = 0.816$

D-W = 0.619

All of the independent variables are significant at the 0.05 level. However, the Durbin-Watson statistic indicates the strong possibility of positive autocorrelation. Nonetheless, we will use these estimates as rough approximations to obtain the price-dependent relationship as shown in (26). Given 1969 values of exogenous variables (N = 199,100,000; Y = \$567,635 million; CPI = 109.8 with a base of 1967 = 100; $Q_0 + I$ = 164.7 million pounds) we have,

$$P = 1.12 \quad (0.99853 \times 10^{-8})Q_{in}. \quad (28)$$

Thus initial values for $\hat{\alpha}$ (1.12) and $\hat{\beta}$(0.99853 × 10^{-8}) have been obtained.

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[25]For any particular year, we may obtain equation (16) if we know the number of traps used per vessel or T/K. Hence, we may easily go from traps (i.e., fishing effort) to vessels, in which the model is specified. The relationship for 1966, derived on the basis of cost data obtained from the National Marine Fisheries Service's Division of Financial Assistance (1969), was 562.8 traps per full time equivalent American lobster boat.

[26]Cost data from the National Marine Fisheries Service's Division of Financial Assistance (1966) reveal the following cost breakdown for a representative lobster boat: operating expenses, \$4,965.16; fixed expenses, \$1,180.20; returns to capital and labor, \$5,825.48. This gives a total of \$12,070.84. The latter figure was updated to 1969 by income increases in Maine to obtain \$13,191.

APPENDIX B.—Economic and Environmental Variables Associated with the Maine American Lobster Fishery, 1897-1906, 1924, and 1928-1972.

Year	Lobster catch by traps	Traps fished	Annual seawater temperature at Boothbay Harbor	Fisher-men	Boats	Catch per trap	Traps per boat	Year	Lobster catch by traps	Traps fished	Annual seawater temperature at Boothbay Harbor	Fisher-men	Boats	Catch per trap	Traps per boat
	Million pounds	*Thousand*	*Degrees, F.*	*Number*	*Number*	*Pounds*	*Number*		*Million pounds*	*Thousand*	*Degrees, F.*	*Number*	*Number*	*Pounds*	*Number*
1897	11.2	234				47.9		1945	19.1	378	47.1	4,195	4,110	50.5	92
1898	12.3	279				44.1		1946	18.8	473	47.3	5,806	5,570	39.7	85
1899	12.7	335				37.9		1947	18.3	516	48.6	6,156	6,037	35.5	85
1900	14.4	327				44.0		1948	15.9	439	46.7[1]	5,354	5,274	36.2	83
1901	14.0	304				46.1		1949	19.3	462	50.1[1]	5,402	5,317	41.8	87
1902	14.3	298				48.0		1950	18.4	430	49.3	5,081	5,075	42.8	85
1903	13.1	268				48.9		1951	20.8	383	51.4	4,542	4,500	54.3	85
1904	12.1	264[1]				45.8		1952	20.0	417	50.2	4,966	4,885	48.0	85
1905	11.1	254	44.4[1]			43.7		1953	22.3	490	52.0	5,164	4,758	45.5	103
1906	15.0	305	44.7			49.2		1954	21.7	488	50.3	5,725	5,694	44.5	86
1924	5.5	154	45.9			35.7		1955	22.7	532	50.0	5,920	5,893	42.7	90
1928	7.1	211	47.0			33.6		1956	20.6	533	48.6	5,929	5,875	38.6	91
1929	6.6	208	45.0			31.7		1957	24.4	565	48.8	5,971	5,894	43.2	96
1930	7.8	205	46.6			38.0		1958	21.3	609	47.4	6,016	5,779	35.0	105
1931	5.4	168	48.4	2,392	2,366	32.1	71	1959	22.3	717	47.0	6,510	6,465	31.1	111
1932	6.1	208	46.8	2,624	2,509	29.3	83	1960	24.0	745	47.9	6,593	6,574	32.2	113
1933	5.9	180	47.5	2,460	2,335	32.8	77	1961	20.9	752	47.3	6,509	6,488	27.8	116
1934	5.4	183	45.6			29.5		1962	22.1	767	46.6	5,673	5,631	28.8	136
1935	7.7	185	46.7	2,501	2,386	41.6	78	1963	22.8	731	47.9	5,703	5,195	31.2	141
1936	5.1	185	45.5			27.6		1964	21.4	754	46.9	5,787	5,349	28.4	141
1937	7.3	186	48.2	2,622	2,473	39.2	75	1965	18.9	789	45.8	5,834	5,455	24.0	145
1938	7.7	258	45.2	2,641	2,497	29.8	103	1966	19.9	776	45.7	5,688	5,330	25.6	146
1939	6.6	260	43.5	2,859	2,704	25.4	96	1967	16.5	705	45.1	5,431	5,099	23.4	138
1940	7.6	222	44.6	2,818	2,616	34.2	85	1968	20.5	733	46.6	5,527	5,195	28.0	141
1941	8.9	194	46.1			45.9		1969	19.8	805	48.0	5,814	5,704	24.6	141
1942	8.4	187	46.6	2,489	2,436	44.9	77	1970	18.2	1,166	48.0	6,316	6,290	15.6	185
1943	11.5	209	45.3	2,542	2,515	55.0	83	1971	17.6	1,264	47.7	6,702	6,635	13.9	191
1944	14.1	252	46.4	2,934	2,860	56.0	88	1972	16.3	1,247[2]	47.1	7,117		12.8	

[1]Estimated from partial records.
[2]Preliminary estimate.

Source: *Fishery Statistics of the United States* and Robert Dow.

Appendix C.—Age of Maine Lobster Fishermen.

Age	*Full-Time Lobster Fishermen						**Part-Time Lobster Fishermen					
	1964		1968		1971		1964		1968		1971	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Under 15	22	1	37	2	62	4	166	8	228	12	468	9
15-19	119	6	89	5	89	6	318	16	283	15	575	11
20-24	133	7	112	6	122	9	146	7	191	10	454	9
25-29	173	9	162	9	134	10	156	8	144	8	496	10
30-34	182	9	163	9	115	8	149	7	142	7	407	8
35-39	217	11	172	10	132	9	169	8	134	7	401	8
40-44	228	12	210	12	119	9	149	7	147	8	423	8
45-49	232	12	201	11	145	10	158	8	153	8	407	8
50-54	206	10	208	12	144	10	133	7	138	7	416	8
55-59	191	10	154	9	121	9	136	7	99	5	340	7
60-64	133	7	138	8	82	6	111	6	90	5	292	6
Over 64	127	6	145	8	134	10	198	10	152	8	454	9
Totals	1,963		1,791		1,399		1,989		1,901		5,133	

*Full-time fishermen are those who obtain their licenses prior to April 1.

**Part-time fishermen are those who obtain their licenses after May 22.

The 1964 part-time fishermen sample represents 52% of the total part-time fishermen for that year.
The 1968 sample represents 51% of the total for that year.
The 1971 sample represents 100% of the total for that year.

The full-time fishermen for all three years are 100% samples.

Appendix D.—Economic and Environmental Variables Associated with the Canadian-American Lobster Fishery (Newfoundland to New York) 1939-71.

Year	Boothbay Harbor Temperature °C.	Total Traps in Thousands	Total Catch—Newfoundland to New York — in Metric Tons	Year	Boothbay Harbor Temperature °C.	Total Traps in Thousands	Total Catch — Newfoundland to New York — in Metric Tons
1939	6.4	2,452	20,362	1956	9.2	3,033	34,974
1940	7.0	2,186	18,345	1957	9.4	3,073	33,417
1941	7.8	1,825	17,555	1958	8.5	3,053	31,221
1942	8.1	1,813	19,054	1959	8.3	3,292	33,232
1943	7.4	1,794	21,403	1960	8.9	3,384	35,932
1944	8.0	1,860	24,264	1961	8.5		33,105
1945	8.4	2,103	28,468	1962	8.1		33,143
1946	8.5	2,354	29,414	1963	8.8		32,448
1947	9.2	2,504	26,968	1964	8.3	3,654	31,136
1948	8.2	2,434	27,113	1965	7.7		29,553
1949	10.1	2,428	30,618	1966	7.6		28,411
1950	9.6	2,483	32,843	1967	7.3		25,881
1951	10.8	2,473	34,259	1968	8.1		29,028
1952	10.1	2,520	32,852	1969	8.9	3,936	30,221
1953	11.1	2,586	33,472	1970	8.9	[1]4,962	27,556
1954	10.2	2,926	33,201	1971	8.7	[1]5,634	28,360
1955	10.0	2,707	34,605				

[1]Estimated from incomplete records.

Appendix E.—Ranking (Lowest Average Cost to Highest Average Cost per Unit of Output) of Sample Lobstermen.

Rank	Average cost	Age	Education	Days lobstering	Group number*	Rank	Average cost	Age	Education	Days lobstering	Group number*
1	.0000	52	12	62	1	41	.1789	14	10	56	4
2	.0564	21	15	70	4	42	.1840	34	12	92	2
3	.0593	65	5	48	4	43	.1866	68	7	50	4
4	.0612	56	8	120	3	44	.1872	45	8	72	1
5	.0640	65	12	120	4	45	.1920	39	7	160	3
6	.0640	71	9	60	4	46	.1920	38	10	120	3
7	.0779	54	9	80	3	47	.1920	29	12	160	2
8	.0846	44	8	72	2	48	.1968	40	10	32	1
9	.0906	59	12	136	3	49	.2070	36	12	160	3
10	.0928	61	9	81	3	50	.2073	28	16	108	1
11	.0932	32	12	140	2	51	.2142	34	7	95	2
12	.0960	58	7	80	3	52	.2153	17	11	72	4
13	.1012	25	8	81	2	53	.2164	49	8	110	1
14	.1032	67	7	60	4	54	.2182	27	13	85	1
15	.1032	49	12	123	3	55	.2193	59	8	160	3
16	.1201	48	9	160	3	56	.2262	31	9	66	1
17	.1233	80	8	96	4	57	.2266	18	11	110	4
18	.1252	33	7	54	2	58	.2304	51	12	36	1
19	.1252	43	12	36	1	59	.2352	60	12	126	3
20	.1280	45	8	112	3	60	.2356	65	8	104	4
21	.1280	56	8	80	3	61	.2420	15	9	36	4
22	.1400	38	12	160	3	62	.2429	39	8	156	3
23	.1480	24	10	108	2	63	.2476	27	11	96	1
24	.1512	28	8	84	2	64	.2560	24	12	80	1
25	.1536	72	5	96	4	65	.2580	18	12	80	1
26	.1536	16	10	36	4	66	.2600	43	12	130	1
27	.1555	66	20+	48	4	67	.2664	22	15	70	4
28	.1570	54	9	160	3	68	.2666	16	11	50	4
29	.1600	12	6	20	4	69	.2704	69	7	84	4
30	.1632	65	9	136	4	70	.2742	35	8	160	1
31	.1645	35	7	80	3	71	.2754	48	8	168	3
32	.1664	70	9	48	4	72	.2860	37	12	110	1
33	.1680	67	10	72	4	73	.2880	19	13	56	4
34	.1680	18	13	16	4	74	.2892	71	8	140	4
35	.1685	47	12	56	1	75	.2940	37	12	105	1
36	.1713	37	12	120	3	76	.2960	27	8	108	2
37	.1744	47	8	160	3	77	.3009	36	7	62	3
38	.1752	56	9	84	3	78	.3016	18	11	44	1
39	.1756	73	9	128	4	79	.3064	61	8	144	3
40	.1789	16	9	56	4	80	.3072	14	9	96	4

Source: Bell, Frederick W. and Richard Fullenbaum, "The Regional Impact of Resource Management", File Manuscript No. 117, Economic Research Division, National Marine Fisheries Service, 1972. (Unpubl. manuscr.)

Appendix F.—Parametric Assumptions Used to Generate Relation between Yield Per Recruit and Fishing Mortality.

A	B	C	D	E	F
$M = 0.2664$	$M = 0.1000$	$M = 0.2664$	$M = 0.2664$	$M = 0.2664$	$M = 0.1000$
$W_{\infty} = 12{,}235$	$W_{\infty} = 12{,}235$	$W_{\infty} = 12{,}235$	$W_{\infty} = 12{,}235$	$W_{\infty} = 12{,}235$	$W_{\infty} = 12{,}235$
$K = .04785$	$K = .04785$	$K = .04785$	$K = .02392$	$K = .04785$	$K = .04785$
$t_0 = -.77250$	$t_0 = -.77250$	$t_0 = -.77250$	$t_0 = -.77250$	$t_0 = -.38625$	$t_0 = -.77250$
$t_c = 7.0$	$t_c = 7.0$	$t_c = 7.0$	$t_c = 7.0$	$t_c = 7.0$	$t_c = 7.0$
$t_r = 6.0$	$t_r = 6.4$	$t_r = 4.0$	$t_r = 4.0$	$t_r = 4.0$	$t_r = 4.0$

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648 Weight loss of pond-raised channel catfish (*Ictalurus punctatus*) during holding in processing plant vats. By Donald C. Greenland and Robert L. Gill. December 1971, iii + 7 pp., 3 figs., 2 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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