SUPPLY, SUSTAINED YIELD, AND MANAGEMENT OF THE MAINE LOBSTER RESOURCE

By Robert L. Dow*

INTRODUCTION

Biological, environmental, and economic data have been assembled for presentation in the sequence of their relevancy to an understanding of the Maine lobster fishery and the resource which supports that fishery.

Specifically the data consist of landings statistics (tables 1, 2, 3, 11), annual average number of traps fished as an indicator of effort (tables 2, 11), average landed value (tables 3, 10), estimates of fishing and natural mortality rates from stratified sampling of catch (tables 4, 5), length-frequency measurements for estimates of recruitment rate (table 6), estimates of total available legal supply (table 7), and sea water temperatures recorded at Boothbay Harbor by the U. S. Fish and Wildlife Service (tables 8, 9, 11). Data are presented in terms of their inter-relationships.

The purpose is to demonstrate the use of biological, economic, and environmental information to (1) forecast relative abundance and available supply (tables 9a, 10a), (2) monitor changes in the population (tables 9, 10), and (3) recommend a type of management which would permit sustained annual yield of the fishery at or near optimum levels (table 14, fig. 5).

DISTRIBUTION AND LIFE HISTORY

The American lobster, Homarus americanus, the largest and commercially most important crustacean in Maine waters, supports the seventh most valuable United States fishery and brings the highest unit price of any major species in North America. These economic facts have been important considerations in appraising the biological condition of the resource and in predicting available abundance, both present and future.

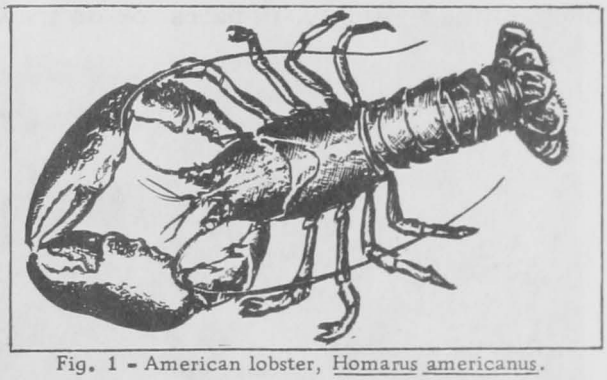

Fig. 1 - American lobster, Homarus americanus.

The lobster is especially abundant in Maine and Nova Scotia and occurs elsewhere in smaller numbers, both inshore and offshore, from Labrador to the Middle Atlantic.

At periodic intervals throughout life, varying with the rate of growth and commencing at the end of the first larval stage, the lobster moults. Although individual lobsters may moult at any season, for the majority this debilitating experience takes place sometime between May and September. In Maine there is a geographical variation; moulting occurs about six week earlier in western Maine waters than in the extreme eastern portions of the coast.

Shortly after moulting, while the new shell is soft, the mature female is impregnated 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 swimmerettes under the tail. The number of eggs produced varies geometrically with the size of the female; the range reported from measurements at Boothbay Harbor (Taylor 1950) was from approximately 6,000 to 40,000 eggs for lobsters with a carapace from $3\frac{1}{4}$ to 5 inches. During the warm months of the following year the eggs complete incubation and hatch.

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The length of the larval period varies largely with sea water temperature from a minimum two weeks at 68°-70° F. to a theoretical maximum of approximately two months with low temperatures. Young lobsters become permanent bottom residents with the fifth larval stage.

Living on the ocean bottom, among and under the 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.

THE FISHERY

The record of 64 years of landings in table 1 shows the wide variation in production from 5 million to nearly 25 million pounds.

Table 1 - Maine Lobster Landings, Selected Years 1880-1963

Year	Millions of Pounds	Year	Millions of Pounds	Year	Millions of Pounds	Year	Millions of Pounds
1963	22.8	1947	18.3	1931	5.4	1906	15.0
1962	22.1	1946	18.8	1930	7.8	1905	11.1
1961	20.9	1945	19.1	1929	6.6	1904	12.1
1960	24.0	1944	14.1	1928	7.1	1903	13.1
1959	22.3	1943	11.5	1924	5.5	1902	14.3
1958	21.3	1942	8.4	1919	5.8	1901	14.0
1957	24.4	1941	8.9	1916	10.2	1900	14.4
1956	20.6	1940	7.6	1915	11.5	1899	12.7
1955	22.7	1939	6.6	1914	12.9	1898	12.3
1954	21.7	1938	7.7	1913	12.2	1897	11.2
1953	22.3	1937	7.3	1912	16.3	1892	17.6
1952	20.0	1936	5.1	1911	16.2	1890	20.0
1951	20.8	1935	7.7	1910	19.9	1889	24.5
1950	18.4	1934	5.4	1909	17.0	1888	21.7
1949	19.3	1933	5.9	1908	17.6	1887	22.9
1948	15.9	1932	6.1	1907	17.4	1880	14.2

The lobster fishery in Maine waters is carried on by means of pots or traps attached to buoyed lines--singly, in pairs, or on trawls. Pots or traps, similar to their probable progenitors (the creels fished in the waters of northwestern Europe and the British Isles), permit some selectivity, but in general, are inefficient. In terms of their return, the pots used require extensive capitalization. Traps or pots used alone represent about $10 million in time, labor, and investment. About the same amount is invested in boats, motors, and other equipment.

Fig. 2 - Lobster traps stacked up at Baily Island, Me.

The fishery in Maine waters began about 1843, primarily to supply canneries. There are reports of earlier use of the lobster resource for cod bait and for fertilizer.

Relatively few changes in the methods of fishing have been developed. Associated equipment such as depth recorders and improved boats and motors permit the individual fisherman to operate in a greater area and for a longer season, but in general the fishery has seen little change.

FLUCTUATIONS IN PRODUCTION

Studies have shown that major long-term fluctuations in Maine lobster landings can be attributed to variations in fishing effort (Dow 1961), of which the number of traps being fished is the most consistent index. This relationship is indicated by table 2.

Table 2 - Average Annual Fishing Effort (Units of Gear) and Total Annual Maine Lobster Landings for Selected Years

Year	Effort (Number of Traps)	Landings
	1,000	Millions of Lbs.
1924	154	5.5
1933	180	5.9
1937	186	7.3
1941	194	8.9
1897	234	11.2
1944	252	14.1
1902	298	14.3
1906	305	15.0
1950	430	18.4
1953	440	22.3
1955	532	22.7
1957	565	24.4

Table 3 - Average Annual Landed Value and Total Annual Maine Lobster Landings for Selected Years

Year	Landed Value	Total Landings for Years
	¢/Lb.	Millions of Lbs.
1934	16	5.4
1940	17	7.6
1941	18	8.9
1916	22	10.2
1943	26	11.5
1944	29	14.1
1947	37	18.3
1946	38	18.8
1945	41	19.1
1952	43	20.0
1956	44	20.6
1958	49	21.3
1962	51	22.1
1963	55	22.8

Short-term fluctuations are generally attributed to other factors, both economic and biological. The most important economic consideration is the price paid fishermen for their catch. The consistent influence of average price on lobster production is shown in table 3.

FEEDING AND GROWTH

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.

The lobster is a comparatively slow-growing animal and is believed to be long-lived. Moulting depends upon growth and growth depends largely upon food intake. The frequency of feeding appears to be related to general activity which is influenced by water temperature. Post-moult feeding activity is high and is generally associated in Maine with seasonally high sea water temperatures. Those conditions concentrate the catch of lobsters in the five-month 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, although the average is about 14 percent in length and 50 percent in weight. From studies made in Maine (Taylor & Baird 1947, and Taylor 1949), it is likely that the most precocious lobsters in Maine waters reach minimum legal size when they are 4 years 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 years old, while another small percentage may be 9 years of age or older before they reach minimum legal size.

Fig. 3 - A Maine lobster fisherman returns a sublegal lobster to the water.

MORTALITY

Stratified sampling of the catch supports the assumption that the resource is intensively exploited. A summary of those data arranged by moult-class groups is given in table 4. Natural and fishing mortality rate amounted to approximately 83 percent for recruits and 86 percent for the more catchable next larger (1st moult) size.

Table 4 - Total Lobster Mortality Rate and Percentage of Catch by Lobster Size Groups, 1949-1956

Carapace Size in Inches	Number of Lobsters Measured	Percentage of Catch	Percentage Decrease
		..... (%)	
$3\frac{1}{8}$ to $3\frac{1}{2}$ (recruits)	239,537	84	-
$3\frac{5}{8}$ to $4\frac{1}{8}$ (1st moult)	40,637	14	83
$4\frac{1}{4}$ to $4\frac{3}{4}$ (2nd moult)	5,552	2	86
$4\frac{7}{8}$ to 5 (3rd moult)	478	-	-
Total	286,204		

Table 5 - Natural Mortality

Carapace Size in Inches	Number of Lobsters	Percentage Decrease by $\frac{1}{8}$-Inch or Three-Month Intervals
$3\frac{1}{8}$	68,578	-
$3\frac{1}{4}$	63,908	6.9
$3\frac{3}{8}$	58,611	8.3
$3\frac{1}{2}$	48,440	-

Natural mortality appears to vary, but probably ranges from about 28 to 33 percent a year, as indicated by the data in table 5. Estimates are based on assumed annual moult in which carapace linear increment is approximately 14 percent.

SUPPLY

Until about 1958 the supply of lobsters had generally been adequate to meet demand requirements. It is now becoming increasingly evident that nearly all of the available legal population is being caught each year.

Annual landings have averaged 22 million pounds for the past 13 years. Landings have fluctuated from 20 to 24.4 million pounds during that period. Sampling showed that 79 percent of the catch in 1947 was made up of previously sublegal lobsters that became legal as a result of moulting. By 1952, that number had increased to 85 percent (table 6) and by 1953 to 86 percent. Since that time, it has been estimated that the amount has gone as high as 90 percent or more in some years. Landings have increased approximately 3 percent in weight for each percentage increase in the number of recruits in the catch.

Table 6 - Fishing Effort, Landings, and Composition of Catch in Maine Lobster Fishery

No. of Traps	Annual Landings	Percentage Recruits in Catch
		%
365	17.5	
	18.3	79
	18.8	80
437	19.2	
447	19.4	82
	20.1	84
	21.4	85
464	22.0	86
560	22.3	
745	22.3	

To catch the remaining supply--that is, for the catch to consist entirely of previously sublegal, moult-recruited stock--would require an eightfold increase in fishing effort even if the resource could support such an intensive fishery.

Estimates, based on the 1947-1956 sampling, indicate that the annual available legal lobster supply has varied from 23 to 28 million pounds as a result of differences in the rate of growth and recruitment. During the period 1951-1963, the average available legal supply of lobster in Maine has been calculated to have been 26 million pounds, with a range from 25 to 28 million.

Table 7 - Estimated Maine Lobster Supply

Fishing Effort (Average No. of Traps)	Percentage Recruits in Catch	Average Annual Landings
1,000	%	Millions of Lbs.
928	87	22.5
1,220	89	23.5
1,604	90	24.0
2,109	92	25.0
2,773	94	26.0
3,646	96	27.0
4,793	98	27.5
6,300	100	28.0

From those data, estimates of future production at varying levels of fishing effort based on catch composition and sea water temperature conditions of the period 1947-1956 are shown in table 7.

SEA WATER TEMPERATURE

The influence of fluctuations in sea water temperature appears to be most pronounced during the spring prior to moulting and subsequent recruitment to the legal-size range. The

Table 8 - April (1)-May (2) Sea Water Temperature and July-August Maine Lobster Landings for Selected Years

Year	Temperature	Landings
	°F.	Millions of Lbs.
1953	50.0	8.1
1955	48.6	8.3
1954	48.5	8.1
1957	48.0	7.8
1952	47.6	7.1
1960	46.6	6.5
1958	45.8	6.0
1956	45.0	5.1
1959	44.8	5.3
1961	44.5	4.7

Note: Use of "April (1)-May (2)" is based on the assignment of 1 value of April sea water temperature to 2 of May.

relationship of temperature to catch at the beginning of the new lobster year is shown in table 8.

That temperature influences are largely seasonal is indicated by table 9.

Fig. 4 - Winter scene on the east side near the Boothbay Harbor freezer wharf.

Table 9 - Relation of April (1)-May (2) Sea Water Temperature and Maine Lobster Landings During Subsequent Periods, 1953-1963

Year	April-May Temperature	Landings						
		July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	°F.	(Millions of Lbs.)						
1953	50.0	3.4	4.7	4.1	2.6	1.9	1.5	18.2
1955	48.6	2.9	5.4	4.8	2.8	1.9	1.1	18.9
1954	48.5	2.9	5.3	4.1	2.9	1.9	1.1	18.2
1957	48.0	3.0	4.8	4.5	4.0	2.6	1.6	20.5
1960	46.6	2.3	4.2	4.9	4.1	2.5	1.5	19.5
1963	46.3	2.1	3.5	4.1	4.3	2.5	1.6	18.1
1958	45.8	2.2	3.8	4.2	3.2	2.2	1.4	17.0
1956	45.0	1.3	3.8	4.5	4.1	2.3	1.4	17.4
1959	44.8	1.9	3.4	4.7	3.9	2.6	1.5	18.0
1961	44.5	1.6	3.0	3.7	4.0	2.5	1.9	16.7
1962	44.3	1.9	3.6	4.7	4.2	2.7	1.2	18.3

METHODS OF PREDICTING AVAILABLE SUPPLY AND LANDINGS

From the data in table 9, tables for predicting lobster landings, available supply, and relative abundance were constructed (table 9a).

Table 9a - Tables for the Prediction of Maine Lobster Landings; Assessment of Relative Abundance and Availability by the Use of Sea Water Temperature

April-May Sea Water Temperature	Landings in Certain Months						
	July	Aug.	Sept.	Oct.	Nov.	Dec.	6 Months Total
°F.	(Millions of Lbs.)						
50.0	3.4	5.3	4.1	2.6	1.9	1.1	18.4
49.0	3.3	5.3	4.1	2.8	1.9	1.1	18.5
48.5	3.0	5.3	4.1	3.0	2.0	1.1	18.5
48.0	2.9	4.8	4.2	4.0	2.5	1.5	19.9
47.5	2.5	4.5	4.2	4.0	2.5	1.5	19.2
46.5	2.3	4.2	4.2	4.1	2.5	1.5	18.8
46.3	2.2	3.8	4.2	4.2	2.5	1.5	18.4
46.0	2.2	3.8	4.2	4.2	2.5	1.5	18.4
45.0	1.9	3.8	4.5	4.2	2.5	1.5	18.4
44.8	1.9	3.4	4.7	4.2	2.6	1.5	18.3
44.5	1.7	3.2	4.7	4.2	2.6	1.6	18.0
44.3	1.6	3.2	4.7	4.2	2.7	1.6	18.0
Standard Error	±11.45%	±5.95%	±9.90%	±7.76%	±4.90%	±14.31%	±4.04%

Unfortunately the tables do not include available supplies and landings during the first s months of the calendar year, nor do they account for variations in fishing effort associated with differences in seasonal price paid fishermen for their catch.

The influence of supply on landed value and of landed value on fishing effort as indicate by subsequent landings is shown by table 10.

Table 10 - July-August Lobster Landings and Prices in Relation to Landings of the Following Year

Year	April-May Temperature	July-Aug. Landings	July-Aug. Price	Year	Jan.-June Landings	Jan.-Dec. Landings
	°F.	Million Lbs.	¢/Lb.		(Million Lbs.)	
1953	50.0	8.1	33	1954	3.6	21.7
1955	48.6	8.3	32	1956	3.2	20.6
1954	48.5	8.1	34	1955	3.8	22.7
1957	48.0	7.8	35	1958	4.4	21.3
1952	47.6	7.1	42	1953	4.1	22.3
1960	46.6	6.5	44	1961	4.3	20.9
1963	46.3	5.6	60	1964	-	-
1958	45.8	6.0	50	1959	4.4	22.3
1956	45.0	5.1	50	1957	4.1	24.4
1959	44.8	5.3	51	1960	4.5	24.0
1961	44.5	4.7	59	1962	3.8	22.1
1962	44.3	5.6	53	1963	4.7	22.8

Modifications of these data for use as prediction tables are shown in table 10a.

Table 10a - Tables for the Prediction of Maine Lobster Landings and Relative Abundance Based on Demand Modified by Sea Water Temperature

April-May Temperature	July-Aug. Landings	July-Aug Price	Year Following	
			Jan.-June	Jan.-Dec.
°F.	Million Lbs.	¢/Lb.	(Million Lbs.)	
50.0	8.3	32	3.2	20.5
49.0	8.2	33	3.6	21.5
48.5	8.1	34	3.8	22.0
48.0	7.8	35	4.0	22.0
47.5	7.1	42	4.1	22.5
46.5	6.5	44	4.3	22.5
46.3	6.0	50	4.4	22.5
45.8	5.8	51	4.5	22.5
45.0	5.6	53	4.5	24.5
44.8	5.3	55	4.6	24.0
44.5	5.1	57	4.7	23.0
44.3	4.7	60	4.9	22.0
Standard Error	±6.93%	±5.13%	±3.96%	±4.52%

Table 11 - April-May Sea Water Temperature (Boothbay Harbo and Annual Lobster Landings (York County)

Year	April-May Sea Water Temperature	Change from Preceding Year	Predicted Landings	Landings
	°F.	± in °F.	Million Lbs. 1/	Million Lbs.
1962	44.3	- .2	1.4	1.5
1961	44.5	-2.1	1.5	1.5
1960	46.6	+1.8	1.7	1.7
1959	44.8	-1.0	1.4	1.5
1958	45.8	-2.2	1.6	1.4
1957	48.0	+3.0	1.7	1.8
1956	45.0	-3.6	1.4	1.5
1955	48.6	+ .1	1.5	1.6
1954	48.5	-1.5	1.5	1.5
1953	50.0	+2.4	1.4	1.6
Standard Error ±7.70%				

1/ Based on ±5% fluctuation with each °F. change in temperature

Since supply in recent years has been inadequate to meet demand, biological and envi mental factors have become increasingly critical. Demand has increased and will rema high for the forseeable future. Methods of precise prediction of future supplies will have be based on sea water temperature with its influence on the rate of growth and recruitmen and the level of fishing effort, rather than on price factors alone. With the current level o fishing intensity the effects of environmental changes on supply will become evident as de tions from predicted availability and relative abundance. Evidence of the past 13 years su gests that available abundance fluctuates approximately 5 percent with each degree of Apri May temperature change.

Application of this evidence to probably the most intensive lobster fishery in Maine, th of York County, for purposes of prediction, and an evaluation of the accuracy of the predic tions is shown in table 11.

EFFORT, TEMPERATURE, AND PRODUCTION

The relationship among annual landings, sea water temperature, and fishing effort is best illustrated by table 12 in which various levels of production are shown with the effort and temperature which produced them.

Table 12 - Relationship Among Annual Landings, Sea Water Temperature, and Fishing Effort

Year	April-May Temperature	No. of Traps	Landings
	°F.	1,000	Million Lbs.
1957	48.0	565	24.4
1960	46.6	745	24.0
Average	47.3	655	24.2
1953	50.0	440	22.3
1955	48.6	532	22.7
1963	46.3	731	22.8
1959	44.8	717	22.3
1962	44.3	767	22.1
Average	46.8	636	22.4
1954	48.5	488	21.7
1958	45.8	609	21.3
1961	44.5	752	20.9
Average	46.3	616	21.3
1952	47.6	417	20.0
1956	45.0	533	20.6
Average	46.3	475	20.3

With sea water temperature influencing seasonal supply and landed value influencing effort, fishermen have generally responded to changes in temperature by adjustments in effort.

Table 13 - Fluctuations in April-May Sea Water Temperature and Corresponding Changes in Fishing Effort to Maintain Constant Production, 1941-1963

Temperatures	Number of Traps
°F.	1,000
-5.7	+327
-5.2	+277
-4.4	+369
-4.3	+235
-4.2	+279
-3.9	+150
-3.8	+185
-3.7	+291
-3.7	+229
-3.1	+226
-2.7	+121
-2.6	+116
-2.3	+199
-1.7	+ 95
-1.5	+180
-1.5	+ 48
-1.4	+ 92
-1.3	+143
- .5	+219
- .5	+ 50
+ .3	+ 43
+ .4	- 7
+ .7	- 86
+1.0	- 43
+1.5	+ 14
+2.0	+ 84
+3.7	- 11

Although this relationship is less precise than it is with some other factors, it does indicate a collective response, conscious or otherwise, of fishermen to temperature fluctuations. A summary of this relationship is shown in table 13.

Since 1941 there have been 27 paired years in which landings have fluctuated 600,000 pounds or less, averaging no more than 3 percent. The relationship of declining effort to increases in temperature or relatively minor changes in temperature and of greatly increased effort to major declines in temperature is illustrated by table 13.

SUSTAINED YIELD

Examination of all the data and their relationships suggests that under existing legal and social conditions of the fishery, a sustained annual yield of 22 million pounds is possible by the proper application of this information.

Sampling of fishermen for the length of the fishing year indicates an average of 130 days. With fishing effort ranging from 383,000 to 800,000 traps and having an average 6.5 percent increase per year since 1951, despite some declines in temperature, the data from table 13 have been used to construct the graph shown in figure 5 as well as to prepare table 14.

Selected pairs of years in which average landings ranged from 21.5 to 22.5 million pounds have been used to find out what fishing effort (number of traps) has to be used at any given April-May sea water temperature level between 44.5° and 49.5° F. to produce 22 million pounds of lobster.

The curve of figure 5 represents sustained yield at 22 million pounds. Deviations as they have occurred within the limits of 21.5 to 22.5 million pounds are indicated. In those years

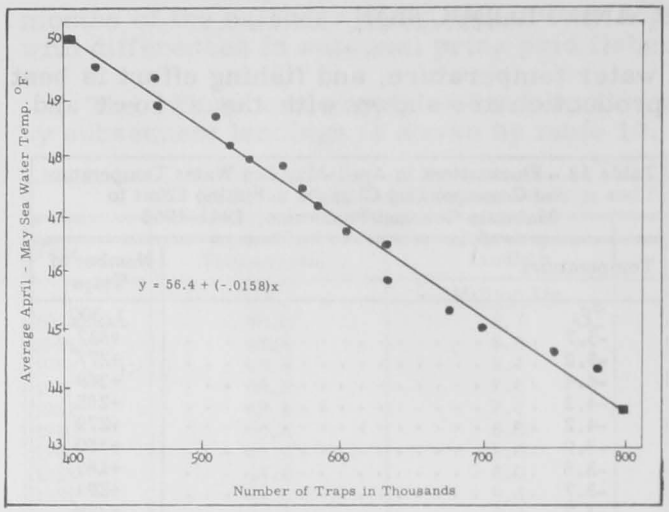

Fig. 5 - Sustained annual yield of 22 million pounds in Maine lobster fishery.

Table 14 - A Type of Management for Sustained Yield in the Maine Lobster Fishery

Years	Average April-May Sea Water Temperature	Average Lobster Landings	Number of Fishing Units (Traps) Needed to Catch 22 Million Pounds
	°F.	Million Lbs.	1,000
1951-53	49.5	21.6	421
1953-54	49.3	22.0	464
1951-55	48.8	21.8	468
1954-55	48.6	22.2	505
1949-57	48.2	21.9	516
1953-58	47.9	21.8	530
1951-60	47.8	22.4	554
1955-58	47.2	22.0	571
1952-60	47.1	22.0	581
1954-59	46.7	22.0	603
1954-62	46.4	21.9	630
1956-60	45.8	22.3	630
1958-59	45.3	21.8	675
1958-62	45.1	21.7	697
1959-61	44.7	21.6	749
1961-62	44.4	21.5	778

when average landings were greater or less than 22 million pounds, the number of traps has been adjusted up or down on a percentage basis.

This application of research findings illustrates how biological and economic information might be used to bring about the ultimate objective of conservation--sustained annual yield of a resource at the best level possible.

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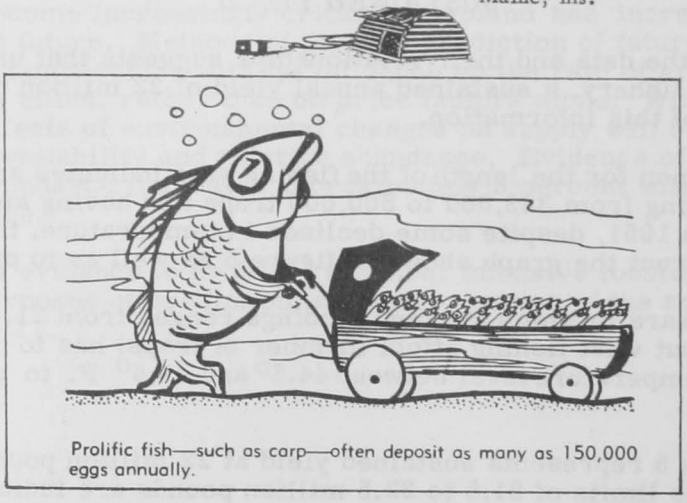

Prolific fish—such as carp—often deposit as many as 150,000 eggs annually.