Lobster, *Homarus americanus*, Trap Design and Ghost Fishing

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INTRODUCTION

The Northeast Fisheries Center of the National Marine Fisheries Service has conducted research on the American lobster, *Homarus americanus*, for many years. Recently, research efforts have been directed toward forming a data base upon which recommendations for management of the inshore and offshore stocks in waters off the New England and Mid-Atlantic coasts can be based. The Center is assembling information on population, size, stock separation and mixing, growth rates, mortality rates, and recruitment indices.

To understand the effects of fishing on the resource, fisheries managers need not only catch/effort statistics and total weight and size composition of removals, but also data on the effects of non-selective and destructive fishing methods. Fisheries engineers and diver/biologists of the Center conducted a series of studies into these latter two factors; the results of this research are contained herein.

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Trap Design and Ghost Fishing: An Overview

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INTRODUCTION

This paper presents necessary background information for the subsequent papers on lobster trap design and ghost fishing in this issue of *Marine Fisheries Review*. A brief review of the lobster fishery and management is followed by a discussion of ghost fishing and escape vents.

RANGE

The American lobster, *Homarus americanus*, is found naturally on the east coast of North America, from North Carolina to Labrador, and is most abundant from Nova Scotia to New York. While most lobster fishing occurs in inshore waters, defined in this paper as all coastal waters extending 30 nautical miles seaward, since the early 1950's the offshore lobster stocks (along the edge of the continental shelf) have been increasingly fished.

THE FISHERY

Lobsters in the inshore fishery are caught mostly in traps or pots (the two terms are used interchangeably) as described by Everett (1972). Offshore lobsters have been harvested using otter trawl nets that are specifically rigged for lobster fishing or that catch lobsters incidentally to fishing groundfish. In 1968 an offshore pot fishery developed using a larger version of the inshore pot (Doliber, 1973:63).

The lobster fishery is the most valuable fishery on the east coast of the United States. In 1969 lobster landings were a record 33.8 million pounds—worth $29 million (Table 1). In New England this represented a 2 percent increase in volume and a 13 percent increase in value over the 1968 landings. A 2 percent decline in catch by inshore pot lobstermen was more than offset by a 29 percent increase in catch by offshore otter trawlers. New York and New Jersey's share of the harvest increased by 20 percent in volume and 24 percent in value over 1968 levels. These increases were due to a more intensive inshore pot fishery which resulted when fishermen diverted their effort from black sea bass, *Centropristis striata*, to lobsters (National Marine Fisheries Service, 1969).

By 1972 the lobster landings were down to 32.3 million pounds, but the value of the catch was in excess of $39 million (Table 2). The inshore pot fishery landed 23 million pounds—a significant drop from the 27 million pounds caught inshore in 1969. However, the offshore landings had increased by nearly 2 million pounds due to increased effort in the offshore pot

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Table 1.—Lobster fishery statistics for 1969 and 1970.

		TOTAL LANDINGS		POT FISHING					OTTER TRAWL -Lobster			(Pounds) Incidental O.T. Landings	REMARKS
		1,000 lbs	1,000 $	Fishermen	Vessels	Boats	Traps	Landings (1,000 lbs)	Fishermen	Vessels	Landings (1,000 lbs)		
1969	ME	19,835	16,047	5,814	35	5,669	819,375	19,835					35 vessels - 402 gross tons total
	N.H.	732	652	261		193	17,160	732					
	MA	4,965	4,741	1,217	7	1,021	132,303	3,455	152	24	1,249	220,500	7 pot vessels - 1,010 gross tons total
	R.I.	4,246	3,787	228	3	185	22,480	892	198	41	3,323	31,200	
	CT	933	945	445	9	364	20,704	804	12	3	126	2,700	
	TOTAL (N.E.)	30,711	26,172	7,965	54	7,432	1,012,022	25,718	362	68	4,698	254,400	
	N.Y.	1,416	1,415	261	17	193	37,195	883	72	18	461	69,100	
	N.J.	1,434	1,212	53	8	24	12,590	974	198	47	329	125,800	
	DE												
	TOTAL (M.A.)	2,850	2,627	314	25	217	49,785	1,857	270	65	790	194,900	
	MD	26	21									21,700	4,800 lbs caught in fish traps
	VA	181	123						37	7	181		
	TOTAL CHESA	207	144						37	7	181	21,700	
	TOTAL	33,768	28,984	8,279	79	7,649	1,061,[illegible]7	27,575	669	140	5,669	471,000	
1970	ME	18,172	17,202	6,326	35	6,289	1,180,000	18,172					
	N.H.	688	722	323		237	17,800	688					
	MA	5,685	5,853	1,334	7	1,092	138,646	4,206	102	16	1,039	397,200	
	R.I.	5,195	5,212	307	5	211	30,257	1,620	185	38	3,561	12,800	5 pot vessels - 396 gross tons total
	CT	673	715	670	9	535	25,719	671				1,800	9 pot vessels - 87 gross tons total
	TOTAL (N.E.)	30,413	29,704	8,960	56	8,364	1,392,422	25,357	287	54	4,600	411,800	
	N.Y.	1,647	1,847	375	25	266	47,070	943	78	21	647	55,900	25 pot vessels - 409 gross tons total
	N.J.	1,836	1,739	63	17	28	15,450	706	211	52	1,035	50,500	17 pot vessels - 171 gross tons total, 43,800 lbs caught in fish traps
	DE												
	TOTAL (M.A.)	3,483	3,586	438	42	294	62,520	1,649	289	73	1,682	106,400	
	MD	22	20						10	2	13	500	7,500 lbs caught in fish traps
	VA	229	149						47	9	98	130,600	
	TOTAL CHESA	251	169						57	11	111	131,100	
	TOTAL	34,147	33,459	9,398	98	8,658	1,454,942	27,006	633	138	5,393	649,300	

Vessel - over 5 tons   Boat - under 5 tons   Small catches by dredges, gill nets, by hand, dip nets, and diving not included fishery. The 1972 offshore pot landings were 6.3 million pounds compared with 115,000 pounds in 1969. Otter-trawl catch declined from 6.8 million pounds in 1969 to 2.4 million pounds in 1972.

The average annual landings between 1971 and 1975 were 30.4 million pounds. In 1976, lobster landings were 31.7 million pounds, worth a record $52.7 million (Robinson, 1977).

Tables 1-3 present an overall review of the lobster fishery, by state, from 1969 to 1974. The data were extracted from *Fishery Statistics of the United States* for the corresponding years, except for 1974 which is unpublished preliminary data.

MANAGEMENT

Because of the rapid decline of the inshore lobster catch and the increasing exploitation of the offshore stocks, methods to manage the resource are being discussed. Such discussions are not new. For over a century, concern for the protection of the American lobster has been shown by both industry and government. Calls for the protection of lobsters are usually stimulated by fear of overfishing to the point of commercial extinction.

Fishermen and researchers alike have considered government regulation of lobster fishing one way to protect the lobster resource since the earliest years of the fishery (Herrick, 1911; Field, 1911). One of the first restrictive pieces of legislation on lobster fishing was enacted in in Sweden in 1686. The first protective legislation for lobsters in this country was formulated in Provincetown in 1812. The Provincetown law required permits for lobster fishing and was actually more concerned with the predator, man, than with the prey. By 1874, overfishing, due to the rapidly rising demand of the canning industry, caused Massachusetts to make it illegal to sell any lobster less than 10.5 inches in overall length. Maine's first lobster laws, like those of Massachusetts, were concerned with residency requirements. In the 1870's, coincidentally with Massachusetts, laws were enacted that restricted canning, but it was not until 1895 that the 10.5-inch lobster regulation terminated canning in Maine entirely.

Since then government regulation has taken many forms. There are laws governing minimum and maximum sizes. Fishing seasons are regulated. There are also many regulations regarding the marketing of lobsters. Egg-bearing females are protected. Even limited entry has been used to restrict the number of Canadian canneries in the last century (Collins, 1904:22).

Other forms of regulations have dealt mainly with the gear used. Many states require that pots and buoys have means of identification as an aid for law enforcement. Some types of gear are banned outright, such as scuba gear in Maine. Otter trawlers are not allowed to operate in certain areas.

Most of these regulations have been attempts to deal with the obvious situations that may cause resource depletion. However, there are some less obvious problems. One of these is "ghost fishing."

GHOST FISHING

Ghost fishing is defined as the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman. This problem was first recognized in gillnet fisheries and was a major topic of discussion at a Food and Agriculture Organization (FAO) meeting in Rome in 1960.

The chief of the Fishing Gear Section of FAO's Fisheries Division stated that bottom-set cod gill nets that were recovered months or years after being lost

Table 2.—Lobster fishery statistics for 1971 and 1972.

	STATE	TOTAL LANDINGS		POT FISHING					OTTER TRAWL-Lobster			(Pounds) Incidental O.T. Landings	REMARKS
		1,000 lbs	1,000 $	Fishermen	Vessels	Boats	Traps	Landings (1,000 lbs)	Fishermen	Vessels	Landings (1,000 lbs)		
1971	ME	17,588	17,481	6,670	34	6,635	1,278,226	17,558					34 vessels - 394 gross tons
	N.H.	667	741	345		240	18,600	667					
	MA	6,146	6,894	1,099	10	873	110,672	4,816	60	10	408	890,600	
	R.I.	5,389	6,038	319	22	202	40,701	2,930	200	41	2,458		22 pot vessels - 8,817 gross tons
	CT	523	657	609	7	427	25,929	521				1,000	
	TOTAL (N.E.)	30,313	31,811	9,042	73	8,377	1,474,128	26,492	260	51	2,866	891,600	
	NY	1,790	2,054	474	35	309	55,325	1,039	79	21	727	23,100	
	NJ	1,323	1,460	123	30	36	31,640	479	179	47	769	35,400	
	DE	30	41	21		9	475	30					
	TOTAL (M.A.)	3,143	3,555	618	65	354	87,440	1,548	258	68	1,496	58,500	
	MD	28	28									23,500	4,600 lbs caught in fish traps
	VA	234	200	19	3		3,200	111				122,300	
	TOTAL CHESA	262	228	19	3		3,200	111				145,800	
	TOTAL	33,718	35,594	9,679	141	8,731	1,564,768	28,151	518	119	4,362	1,095,900	
1972	ME	16,257	18,588	7,039	30	6,974	1,448,365	16,256					
	N.H.	674	809	277		225	15,958	673					
	MA	8,032	10,276	1,204	11	931	145,127	7,077	60	10	410	511,700	4,138 offshore traps caught 2.8 million lbs
	R.I.	3,361	4,319	418	37	241	47,367	2,475	104	22	872	13,400	14,675 offshore traps caught 1.6 million lbs
	CT	540	777	758	2	512	33,761	539				400	
	TOTAL (N.E.)	28,864	34,769	9,696	80	8,883	1,690,578	27,020	164	32	1,282	525,500	
	NY	1,145	1,825	506	33	353	53,150	1,011	62	17	121	11,400	
	NJ	1,308	1,828	171	53	31	42,010	838	120	32	447	15,100	
	DE	22	36	19		8	615	22					
	TOTAL (M.A.)	2,475	3,689	696	86	392	95,775	1,871	182	49	568	26,500	
	MD	21	26	4	1	1	500	15					5,400 lbs caught in fish traps
	VA	884	1,028	33	5		6,000	877				6,100	
	TOTAL CHESA	905	1,054	37	6	1	6,500	892				6,100	
	TOTAL	32,244	39,512	10,429	172	9,276	1,792,853	29,783	346	81	1,850	558,100	

Vessel - over 5 tons Boats - under 5 tons Small catches by dredges, gill nets, by hand, dip nets, and diving not included.

contained numerous fish skeletons and live fish. He referred specifically to an intensive fishery around Iceland that employed synthetic fiber nets fitted with plastic and metal floats—fishing gear that could continue to fish without rotting for long periods (U.S. Department of Interior, 1968).

The solution devised to counter the problem was to hang the nets from the floats with natural fiber twine. If the nets were lost, this twine would rot causing the nets to separate from the floats and sink; thus the gear would no longer be an effective fishing unit (Von Brandt, 1964:168).

The threat of ghost fishing in a pot fishery became a concern in the west coast king crab, *Paralithodes camtschatica*, fishery in the early 1960's. When this fishery began in the 1950's, the first pots were large versions of those used for Dungeness crabs, *Cancer magister*. These pots were covered by natural fiber twines which usually rotted out in less than a season (Rietze, pers. commun.[1]). During the 1960's, pot design evolved; king crab pots are now constructed with steel frames covered with synthetic fiber web, making them highly durable. This durability made it more urgent to answer the question of whether or not lost pots continued to fish and for how long, especially when gear-loss rates were estimated at over 3,000 pots annually (Meyer, pers. commun.[2]).

[1]Harry L. Rietze, Director, Alaska Region, National Marine Fisheries Service, NOAA, P.O. Box 1668, Juneau, AK 99802.

The National Marine Fisheries Service (NMFS) began in 1970 to study the problem of lost king crab pots to determine if they did continue to fish and if trapped crabs could escape. In addition, information was gathered on deterioration rates of different pot web hanging materials (Meyer, footnote 2). The preliminary results of the experiment indicated that king crabs could escape from lost pots. However, the same study reported that lost pots that were recovered often contained as many as 100 live marketable king crabs.

Some observations that gave impetus to the above research were made by McNeely (NMFS, pers. commun.[3]) on a cruise aboard the *John N. Cobb* in January 1970. On this cruise nine experimental sablefish (blackcod), *Anoplopoma fimbria*, pots were recovered which had been lost for 1 month. Six of the pots contained snow crabs (*Chionoecetes*), as many as 32 per pot, and the average catch of sablefish was 12 fish per pot. There were also numerous remains of sablefish in the pots.

Hipkins and Beardsley[4], in a progress report on the development of sablefish pots, felt that ghost fishing of these pots might be a serious problem: "It appears then that blackcod (sablefish) pots (and probably most other pot gear) will continue to fish with dead fish serving as bait to attract new fish which eventually die to attract more fish and so ad infinitum until the pot deteriorates to the point where fish can escape. This process of deterioration is slow and

Table 3.—Lobster fishery statistics for 1973 and 1974.

	STATE	TOTAL LANDINGS		POT FISHING					OTTER TRAWL-Lobster			(Pounds) Incidental O.T. Landings	REMARKS
		1,000 lbs	1,000 $	Fishermen	Vessels	Boats	Traps	Landings (1,000 lbs)	Fishermen	Vessels	Landings (1,000 lbs)		
1973	ME	17,044	23,270	8,151	32	7,863	1,822,490	17,044					
	N.H.	497	680	468		363	22,299	497					
	MA	5,624	8,527	1,093	10	957	159,773	5,120	62	10	260	219,400	6,150 offshore traps caught 1.7 million lbs
	R.I.	2,773	4,235	402	36	228	52,204	2,627	74	15	459		20,375 offshore traps caught 1.7 million lbs
	CT	544	841	514	3	317	27,523	543					
	TOTAL (N.E.)	26,482	37,553	10,628	81	9,728	2,084,289	25,831	136	25	719	219,400	
	NY	892	1,428	494	31	365	52,450	798	56	16	93	800	3,400 offshore traps caught 0.4 million lbs
	NJ	1,363	2,234	175	48	35	40,565	926	73	22	420	7,900	12,965 offshore traps caught 0.4 million lbs
	DE	29	51	41	1	13	764	29					400 offshore traps caught 1,500 lbs
	TOTAL (M.A.)	2,284	3,713	710	80	413	93,779	1,753	129	38	513	8,700	
	MD	24	33	3	1		800	20					3,700 lbs caught in fish traps
	VA	199	285	36	6		6,400	182	5	1	7	10,200	
	TOTAL CHESA	223	318	39	7		7,200	202	5	1	7	10,200	
	TOTAL	28,989	41,584	11,377	168	10,141	2,185,268	27,786	270	64	1,239	238,300	
1974	ME	16,457	23,212	10,628		7,589	1,789,900	16,457					
	N.H.	498	702	402		276	23,105	498					
	MA	5,943	9,103	1,471	42	1,062	170,100	4,993	60	11	950		24,100 offshore traps caught 1.1 million lbs
	R.I.	3,129	5,201	544	41	230	56,500	2,650	82	16	579		23,500 offshore traps caught 1.8 million lbs
	CT	647	1,095	715		515	23,925	647					
	TOTAL (N.E.)	26,674	39,313	13,760	83	9,672	2,063,530	25,245	142	27	1,529		
	NY	730	1,395	554	9	376	56,200	661	49	14	69		5,800 offshore traps caught 0.3 million lbs
	NJ	1,191	1,915	107	14	55	32,700	716	90	18	475		9,700 offshore traps caught 0.3 million lbs
	DE	25	45	43	2	13	1,500	25					
	TOTAL (M.A.)	1,946	3,355	704	25	444	90,400	1,402	139	32	544		
	MD	36	65	9	2	0	2,000	36					all caught offshore
	VA	274	504	20	5	0	3,000	274					all caught offshore
	TOTAL CHESA	310	569	29	7	0	5,000	310					
	TOTAL	28,930	43,237	14,493	115	10,116	2,158,930	26,957	281	59	2,073		

Vessel - over 5 tons   Boat - under 5 tons   Small catches by dredges, gill nets, by hand, dip nets, and diving not included.

[2]Robert Meyer, National Marine Fisheries Service, NOAA, P.O. Box 1638, Kodiak, AK 99615.

[3]Richard McNeeley, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112.

[4]Hipkins, F. W., and A. J. Beardsley. 1970. Development of a pot system for harvesting blackcod (*Anoplopoma fimbria*). A progress report. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Seattle, 31 p. Available at the Northwest & Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Boulevard East, Seattle, WA 98112.

could take years depending upon the materials employed in constructing the pot. The consequence of large numbers of ghost pots fishing in an unregulated manner in competition with fishermen could be catastrophic to the blackcod fishery. The lost pots will continue to fish long after the fishery is uneconomic for the commercial fishermen."

They recommended, as a solution, that a cotton web destruct panel be built into each pot. Subsequently the State of Washington issued a regulation on bottom-fish pots that requires: "A section of one vertical wall must be constructed of cotton fiber or one of the walls of synthetic fiber must be attached to the frame with cotton hangings to permit escapement of fish if the bottom-fish pot is lost (Wash. Dep. Fish. Regs., WAC 220-16-145, 1971).

Canadian fisheries managers, even without experimental evidence, thought it prudent to take action to prevent ghost fishing. Proposed regulations for the developing snow crab, *Chionoecetes opilio,* fishery contained provision that would have required all pots to be fitted with a 12-inch long section of netting laced with degradable material (Cormier, pers. commun.[5]).

Regulations of the State of Florida require that all spiny lobster, *Panulirus argus,* pots be constructed of wood so the pot, when lost, will eventually break and not continue to fish. Sixteen-gauge, 1-inch poultry-wire reinforcement is allowed on the pot side but not on the top or bottom. This reinforcement protects the pot from the "ravages of turtles." Escapable pots, e.g., ice cans and drums, are also permitted in the fishery (Seaman and Aska, 1974:58).

Though preventive regulations exist, the controversy on ghost fishing is far from settled. At a pot fishing and artificial baits symposium held at the University of Washington in March 1972, there was much debate on whether pots can fish unbaited. One king crab fisherman felt that lost unbaited pots do not continue to fish. He thought that a greater problem was lost gill nets (tangle nets) which he has found at times to contain the remains of many king crabs (Jaeger, 1972).

At the same symposium it was stated that Dungeness crab fishermen in the Humboldt Bay, Calif., area were concerned with ghost fishing. Here, too, there was ". . . no sound experimental data as to the catch rate in such ghost pots" (Jaeger, pers. commun.[6]).

An analogous situation existed in Australia in a snapper (*Chrysophrys unicolor*) fishery. Local fishermen were afraid of the deleterious effect pots might have on the fishery and research was undertaken to identify problems. Continued fishing by lost pots was considered a possible problem, but here again no information was available on the many factors related to ghost fishing (Bowen, 1964). (This pot fishery was eventually banned in 1966, mainly due to the fact that the pots scraped along the sea bottom, when hauled, killing large areas of coral.)

In one of the most thorough research projects on pot fishing accomplished to date, factors affecting the performance of the "Antillean" fish trap (Munro et al., 1971) were studied. Many observations were made on catch rates, escapement, and mortality of a variety of species of reef fishes. The researchers found that although up to 50 percent of the entrapped fish eventually escaped, many others died due to physical deterioration, starvation, and predation. This last factor, predation of entrapped animals, has also been reported in the New Zealand rock lobster, *Jasus edwardsii* and *J. verreauxi,* fishery, the predator in this case being *Octopus maorum* (Ritchie, 1972).

The threat of ghost fishing in the New England lobster fishery became a point of concern during the development of the offshore pot fishery. The cruise report of the MV *Delaware* (Cruise 68-05, July 1968) documents the recovery of lost pots:

> "Nineteen pots were recovered in May 26. These pots had been lost on March 17 when all the buoy lines had parted at faulty swaged splices in the wires. The pots had been set in 175- to 210-fathom depths. One of the recovered pots was damaged by the grapnel—an entire side panel was missing. The remaining 18 pots contained a total of 24 lobsters which weighed 156.5 pounds—this is a catch rate of about 8.7 pounds per pot. All of the lobsters were quite large and they undoubtedly would have exceeded the 6.5-pound average weight if it had been possible to weigh them when they were first caught instead of after the extended period of starvation through which they had passed. The volume of meat within the lobster shells was exceedingly small for the size of each shell; one very large lobster had thrown both claws—the blackened remnant of the crushing claw was still in the pot with the lobster."

Experiences such as this, by both researchers and commercial fishermen, became more common as the fishery developed.

In November of 1971, McRae prepared material for an International Commission for the Northwest Atlantic Fisheries (ICNAF) advisory committee meeting that recommended action be taken to prevent the possibility of a ghost-fishing problem in the offshore lobster fishery (McRae, NMFS, pers. commun.[7]). In March of 1972, the Northeast Fisheries Center undertook the task of developing methods to prevent ghost fishing. Concurrently with NMFS research, Sheldon and Dow (1975) conducted a ghost trap experiment in Maine. They concluded that unbuoyed traps continued to fish, and that cannibalism resulted in the deaths of at least 15 percent of the lobsters entering the traps.

Factors Affecting Ghost Fishing

Initial research by the Center, consisting mostly of a literature review, concerned itself with identifying the factors affecting ghost fishing in the

[5]Fisheries and Environment Canada, Ottawa, Ontario, Canada K1A OE6.

[6]Sig Jaeger, North Pacific Fishing Vessel Owner's Association, Fishermen's Terminal, Seattle, Wash.

[7]Ernest McRae, Southeast Fisheries Center, National Marine Fisheries Service, NOAA, 75 Virginia Beach Drive, Miami, FL 33149.

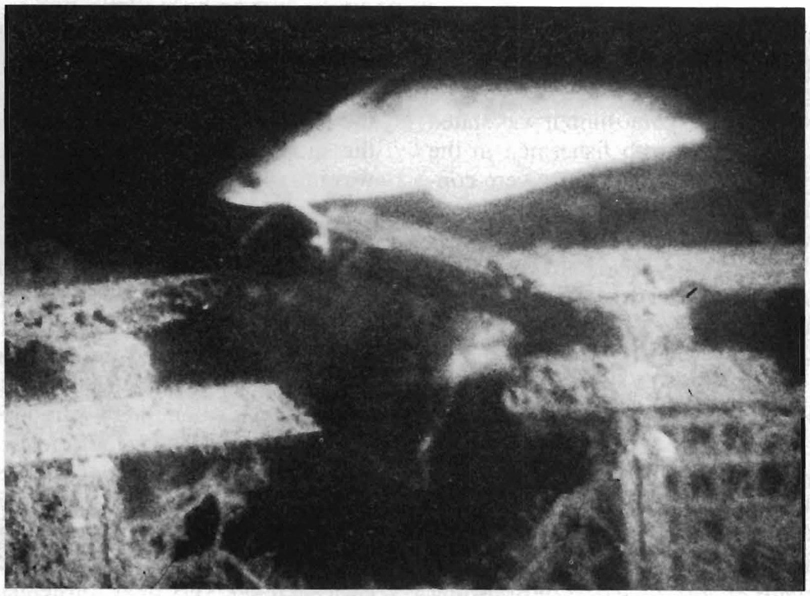

Figure 1.—A photo taken from a submersible at 100 m in Veatch Canyon of a lost trap that was no longer an effective fishing unit. A red hake surveys the scene.

offshore lobster fishery. These parameters were grouped as follows.

Number of pots lost.

By definition, the first criterion that a pot must meet to be considered a ghost pot is that it is lost. A lost pot is not a ghost pot unless it continues to fish after all control is lost. Pot loss in the offshore lobster fishery is caused by vessels inadvertently severing trawl strings, trawl strings become fouled, storms, and gear mechanical failure.

Pot type

The ghost-fishing catch rate is a direct function of how long the pot remains physically intact as an effective fishing unit (Fig. 1). While the offshore lobster fishery had a high pot-loss rate, it used the cheaper, less durable, wood-framed pot. As the loss rate decreases, fishermen tend to switch to highly durable pots.

The size of a pot is also important in assessing ghost fishing. Larger pots usually have higher catch rates.

Other key parameters affecting catch are pot selectivity (size range and species) and the effectiveness of the pot design in preventing escapement. The mortality caused by ghost fishing is directly related to the retention capability of the pot and the pot's selectivity.

Location where lost

The forces acting to destroy a pot as an effective fishing unit vary geographically and with depth. Corrosion rates are a function of interrelated variables such as temperature, depth, oxygen, salinity, and velocity. Biological deterioration varies at different locations and with temperature, velocity, and substrate. A pot can also be destroyed by storm surge or by being buried in the substrate.

The ghost-fishing catch rate varies with the target-species availability at different locations. Ghost-fishing mortality is probably related to the availability of predators and to hydrographic conditions; these two factors are also location dependent.

Target-species behavior

A ghost-pot's catch rate depends on why the target species enters the pot, e.g., bait and/or shelter-seeking behavior. It follows that the pot's retention rate is a function of this behavior as well as of pot design; some pots are designed to be inescapable, while others are hauled before the target species wants to leave.

Ghost-fishing mortality depends on the target species' endurance of the adverse conditions of the pot. There can be self- or conspecific-inflicted injuries caused by behavioral response to the conditions of crowding, starvation, and environmental change.

Preventing and Decreasing Ghost Fishing

Two of the controllable factors affecting ghost fishing are rate of pot loss and pot type.

In the offshore lobster fishery, fishermen have placed much effort into decreasing their pot losses. These fishermen set trawl strings with up to 90 attached pots, sometimes extending over 1.5 km in length, on the ocean bottom. Foreign and domestic trawl fishermen, dragging midwater or bottom trawl nets, often work the same areas as the fixed-gear lobstermen. They sometimes inadvertently tow across the lobster-trawl strings and frequently sever the connections to surface buoys.

A partial solution to this problem has been to concentrate the pots in "pot fields" and report their positions to the Coast Guard. This solution has been further refined by dividing offshore waters into dragging and fixed-gear areas. The concentration of pot fields has led to lobster-trawl strings becoming fouled with each other and being lost. This problem has been reduced by the lobstermen setting their strings parallel to the bottom depth contours.

The above practices by the fishermen, along with experience gained in this new offshore lobster fishery, have decreased the annual pot-loss rate from as high as 100 percent to about 25 percent. This latter figure is comparable to the loss rate in the inshore lobster fishery.

The fishermen's immediate concern for decreasing gear loss is based on the direct economic costs and not a fear of a ghost-fishing problem. Their choice of pots is also based on direct economic costs, the primary variables being durability, handling, and catch rates. It can be assumed that a fisherman will use the most economically efficient pot available. The problem is to design this pot to prevent or reduce ghost fishing if the pot is lost, without introducing inefficiencies into the fisherman's operation. One approach would be to design the pot to selectively retain only legal-sized lobsters. Much research has been accomplished in this area in regard to protecting short lobsters.

Enforcement of size limits has always been a problem (Collins, 1904; Herrick, 1911; Field, 1911). Even today, by conservative estimates, the landed number of short lobsters exceeds 10 percent of legal landings. Though this illegality is difficult to document, it is not necessarily difficult to solve. Solutions available include: 1) increased enforcement pressure, 2) better education of the fishermen on the values of size limits, and 3) sublegal escape vents.

Escape Vents

Pots that contain escape vents could conceivably decrease ghost fishing related injuries and mortality. The word vent is defined here as an opening in a lobster pot, such as the space between the laths. An escape vent is an opening designed into the pot to allow lobsters to escape. The head ring in a pot is the entrance vent, though lobsters may also escape through it.

Sublegal escape vents allow lobsters under the legal minimum size to escape. A legal minimum size requirement is considered an effective biological and economic tool (Wilder, 1954; Thomas, 1973). While there is no consensus of what the optimum minimum size should be, few challenge the fact that size limits are necessary for protection of the lobster stocks.

Sublegal escape vents on lobster pots are not a new idea. The effects of lath spacing on the size composition of the catch has been recognized by fishermen ever since they began building pots.

Some of the earliest recorded scientific experiments on lath spacing were conducted by Adolph Neilsen, Superintendent of Fisheries in Newfoundland, in the 1890's (Templeman, 1958). He established the concept of using lath spacing as a means of regulating the catch of sublegal lobsters.

Newfoundland eventually enacted a law requiring 1¾-inch spacing in pots, but many fishermen were critical of the value of this law. They thought it did not affect the catch of sublegals, that the bait was used up faster, and that legals could escape. In 1938 Templeman conducted experiments demonstrating that pots with the 1¾-inch spacing not only caught 80 percent fewer shorts (9-inch overall length), but were also able to catch more legal-sized lobsters than pots of smaller lath spacing (Templeman, 1939).

Wilder conducted similar experiments between 1943 and 1946 (Wilder, 1943, 1945, 1949). In areas where the legal size of the lobster was 7 inches overall, Wilder found that pots with 1¼-inch lath spacing decreased the catch of sublegals by 60 percent and increased the catch of legals when compared with pots of 1-inch spacing. Where the legal size was 3⅛ inches on the carapace, 1¾-inch lath spaces allowed 75 percent of the shorts to escape without reducing the legal catch. Wilder states that pots with sublegal vents allowed the greatest increase in legal catch where the average size of lobsters caught was large. Where the average size was small, the greatest reduction in captured shorts occurred. In addition, wider-lath pots retained fewer crabs.

Experiments in Western Australia and Tasmania, testing the effectiveness of sublegal escape gaps (vents) on rock-lobster pots, provide results similar to that of the Canadians. Again, pots with escape vents decreased the amount of undersized lobsters caught and increased the catch of legal-sized lobsters (Winstanley, 1970, 1973; Bowen, 1963).

The crab fishermen of California, Oregon, Washington, and Alaska have a self-imposed regulation requiring escape vents in pots (Hipkins, 1972). These vents allow the smaller female crabs to escape. In California, a regulation regarding crab-pot escape-vent size became law effective January 1975.

In August of 1975 the State-Federal Lobster Management Program made up of representatives from New England and the Mid-Atlantic states, recommended that sublegal escape vents be required in all lobster traps. The recommendations, based in part on unpublished data from this study, and from Krouse and Thomas (1975), were subsequently promulgated as regulations by Massachusetts and Maine.

The advantages of sublegal escape vents in the northern lobster fishery have been summed up by Templeman (1958) as follows:

> "(a) the lessening of the temptation to sell illegal small lobsters and the reduction of the number of shorts available to fishermen who illegally retain these lobsters; (b) the saving of considerable time in picking short lobsters and crabs out of traps; (c) a decrease in injuries to short lobsters by rough handling and from encounters with larger lobsters in the confined space of the traps; (d) a probable reduction in the loss of small lobsters which may be eaten by cod and other fishes, either on their way down from the surface after being discarded, or because they have been distributed on the bottom, in daylight, in unfamiliar territory without shelter; and (e) if the traps were built with wide spaces all over them, an increase in hauling efficiency, since traps with fewer laths and less ballast, and with wider spacing all over the trap, would be more stable and survive better under turbulent conditions. It is very likely also that this greater stability would increase the catch when the traps are fished in wave-disturbed shallow water."

Sublegal escape vents may effectively decrease ghost-fishing mortality among short lobsters, especially where the catch ratio of shorts to keepers is 10 to 15:1 (Thomas, 1973:4), but do not solve the problem within the legal range. Most of the offshore lobsters caught are of legal size. The approach here may be to have a "catch-escape vent" on each pot that is kept shut by some degradable mechanism. After a specified period of time this mechanism would deteriorate, opening the vent and rendering the pot ineffective, e.g., the cotton panel required on Washington bottom-fish pots.

Another approach to the problem of preventing ghost fishing might be to design an entirely different type of pot that does not depend on the escape-proof trapping of the lobsters. Pots of

Figure 2.—An offshore lobster using a discarded 55-gallon drum as a shelter. Photo taken from a submersible at 200 m in Veatch Canyon.

this variety are used in a number of fisheries where the target animal demonstrates positive thigmotactic response, e.g., eels, octopus, and spiny lobsters (Von Brandt, 1964:58). In the spiny lobster, *Panulirus argus*, fishery of Florida, this type of pot is sometimes constructed out of discarded gasoline drums (Smith, 1958:26).

We coined the name "habipot" for a type of pot that does not depend primarily upon bait attraction or escape-proof trapping of the lobsters but instead captures lobsters by offering an attractive shelter (Fig. 2). Pots of this conceptual design would not ghost fish, and could possibly fish selectively since different-size lobsters apparently prefer different shelters (Cobb, 1971). Unfortunately we were not able to test this concept adequately because of time constraints.

The papers that follow present the results of our field and laboratory experiments.

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