

The "Tuna-Porpoise" Problem: NMFS Dolphin Mortality Reduction Research, 1970-81

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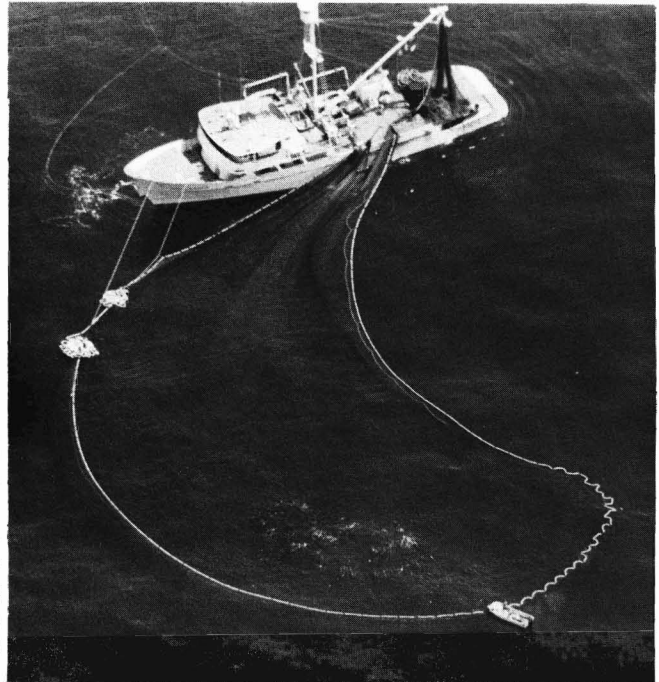
Introduction

Nearly 15 years have passed since the National Marine Fisheries Service (NMFS) first became concerned with reducing incidental dolphin¹ mortality in the U.S. tuna purse-seine fishery. This paper is presented as an overview of NMFS' applied research on this problem. The major portion of this research was conducted at the La Jolla Laboratory of the NMFS Southwest Fisheries Center (SWFC). This paper is not intended to be a complete history of the program, but rather is a summary and index of the major research conducted by the SWFC over the full course of the program's existence from 1970 to 1981. A glossary (Table 1) and a bibliography of NMFS publications and reports on dolphin mortality-reduction research are included.

Background

Purse seining for yellowfin tuna, *Thunnus albacares*, in the eastern tropical Pacific reached commercial proportions in the 1950's (McNeely, 1961). This fishing method involved the incidental deaths of many thousands of dolphins, a fact not widely known until the late 1960's (Perrin, 1969; 1970). In 1969 a modest research program was formed within the National Marine Fisheries Service (then named the Bureau of Commer-

¹Three species of pelagic dolphins (commonly called "porpoise" by tuna fishermen) were primarily involved in this research. They are, in order of decreasing importance, the spotted dolphin, *Stenella attenuata*; spinner dolphin, *S. longirostris*; and the common dolphin, *Delphinus delphis*. Common names in this paper for marine mammals follow the terminology of the International Whaling Commission and the U.S. Marine Mammal Commission.



A typical purse seine during the back-down procedure. The vessel is a 525-ton class III seiner which is beginning backdown with about 200 spotted dolphins in the net.

cial Fisheries) to investigate the specific nature of what has since come to be known as the "tuna-porpoise" problem. From its inception, this research program, located at the NMFS Southwest Fisheries Center, has had a portion of its resources dedicated to research on the reduction of incidental dolphin mortality in the tuna fishery.

The Marine Mammal Protection Act (MMPA) of 1972 charged the

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NMFS with the responsibility of carrying out provisional regulations designed to reduce dolphin mortality and injury to the lowest practicable level. In 1972, while this act was being drafted, NMFS convened a group of marine mammal scientists, fishery biologists, and policy specialists, known as the NOAA Tuna-Porpoise Review Committee, to prepare an action plan addressing the tuna-porpoise problem. The report of this group² provided general guidelines under which virtually all subsequent NMFS dolphin related research has

²Report of the NOAA Tuna-Porpoise Review Committee, Sept. 8, 1972. U.S. Dep. Commer., NOAA, NMFS, Southwest Fish. Cent., La Jolla, Calif., 63 p.

Table 1.—Glossary of tuna seining terms and definitions adapted from F. M. Ralston (editor), 1977. A workshop to assess research related to the porpoise/tuna problem. SWFC Admin. Rep. LJ-77-15, 119 p.

Apex flapper: An experimental modification to the super apron consisting of a series of overlapping, trapezoidal pieces of 1¼-inch mesh. These panels were placed above the corkline at the apex of the backdown channel to provide a visual barrier to the tuna and, at the same time, be permeable to dolphins.

Apron: A trapezoidal appendage sewn to the top edge of the uppermost dolphin safety panel(s) of a purse seine. Before the apron can be installed the corkline must be cut from the safety panel. The corkline is subsequently reattached to the sides (which are equilateral) and the top of the apron, the base of the apron having been attached to the safety panel. The apron produces a ramplike shallowing of the backdown area, reduces canopies, and reduces the incidence of tuna mixing with the dolphins in the release area during backdown.

Backing down (backdown): A process whereby the corkline of the purse seine can be submerged and pulled from under the dolphins with the application of reverse engine power by the seiner. This is a fundamental technique for releasing dolphins from the net.

Bridles: Typically, these are sections of chain that are attached at both ends to the seine chainline. They are cut at a length that allows draping of the bridle below the chainline; a split-link is attached at the center of the bridle and a pursing ring is tied to this link (also see towing bridles).

Bunches: These are large clumps of bunched corkline. They are pulled using an auxiliary bunch-line (like a draw string) that runs through small (3" diameter) rings which are tied to the corkline. Bunches are useful in 1) removing excess slack in the corkline (which can lead to canopies and entrapment) and 2) maximizing the buoyancy of the net going into the sacking-up phase (to prevent sinkage and loss of fish).

Canopy: This is a configuration where the webbing blossoms out beyond the corkline due to currents or other adverse conditions. Dolphins in canopies frequently can't find the way back to the surface to breathe due to the sometimes convoluted shape of the canopy. Canopies can also be caused by net collapses, where the corkline comes together and forces dolphins into contact with the meshes and greatly reduces available surface area.

Chainline (leadline): This is a section of chain that runs the length of the bottom of the net. It is attached to the selvage on the lower edge of the bottom strips of webbing and provides the weight necessary to sink the webbing.

Chute: This is a trapezoidal section of webbing with equilateral sides. It is located atop the apron, but below the corkline. It further optimizes the ramp-formation characteristics of the apron.

Collapse: This is a situation where the corkline comes together, restricting the dolphins' access to the surface. Severe collapse, involving large portions of the net, can result in high dolphin kills. The timely use of speedboats pulling on towing bridles has proven to be an effective measure in reducing the incidence of collapse.

Downhauls (downhaul gate): For this application, a series of rope bridles is attached to the seine's corkline, each attached to a vertical line leading to an anchor point on the webbing directly below. Shortening the vertical line causes the corkline at the bridle above to submerge during the pursing operation to permit dolphin release.

Encirclement: This refers to the stage of the set where the target (either dolphins and tuna, "schoolfish" tuna, or log-associated fish) is surrounded by the net or a combination of the net and towline.

Entanglement: This refers to dolphins being physically stuck in the webbing of the net (or the corkline) by a part of their body such as beak, flippers, flukes, or dorsal fin.

Entrapment: This refers to a situation within the seine where the dolphins are forced into contact with the webbing due to collapse or canopy formation.

Fine mesh: This term is typically used to specify 1¼-inch stretched mesh webbing.

Hand holds: On the purse-seine corkline, spaces between adjacent floats at regular intervals (about 1 fathom) where the webbing is not laced to the corkline. These facilitate the orderly stacking of the corkline during net retrieval but also provide openings where dolphins can become entangled.

Hang-in: This refers to the systematic attachment of webbing to a fixed shorter length of bordering line or chain, usually (in purse seines) in the horizontal plane, to allow the meshes to open vertically (hang) without deforming the bordering line.

Medina panel: This is a 2-inch mesh safety panel that is placed in the net to reduce dolphin entanglement during backdown. Generally one strip deep, it surrounds the apex of the backdown channel, the area where dolphins are most likely to come into contact with the net.

Ortza: This refers to either of the ends of the purse seine which are reinforced. The typical seine net tapers up gradually from the maximum depth to the pointed, wing-like ortzas.

Purse cable: This cable runs through the purse rings, which are connected to the chainline by the bridles. By attaching both ends of this cable to the winch, the rings may be gathered and lifted to the boat. This closes the bottom of the net and precludes subsurface escape of fish.

Purse rings: The rings are attached to the bridles and are gathered by the purse cable. The use of rings permits the pulling and lifting force of the winch to be equally distributed along the chainline during pursing.

Pursing: The process of gathering and lifting the bottom of the net.

Reversed bunchlines: These are ropes that run through small rings which are attached to the corkline of the seine. At one end they are secured to the corkline; a small float is attached to the other end. These lines are 20-50 fathoms long and are arranged so the floats of adjacent bunchlines are close together (1 fathom). A speedboat can secure both end-floats of these lines and, by pulling them away from the net, effectively hold the net, thereby preventing collapse in that area.

Roll-net (net roll): After the net has been pursued, the towing or stern end is led through the power block. The power block begins turning and lifting the net out of the water onto the seiner, where it is methodically stacked for the next set. The net is rolled from the stern ortza until the catch is compressed due to the diminishing underwater volume. This results in the catch being rolled into the sack (which is near the bow ortza). In sets involving dolphins, the net is rolled until the amount of net left in the water is proper for backdown. The roll-net process stops, the net is tied down, backdown takes place, and roll-net begins again.

Roll-up: A roll-up is a recurring type of malfunction whereby webbing and cable become tangled and usually results in a delay of the set (described in text above). The period of time needed to remedy the roll-up varies as a function of its severity and can last from a few minutes to several hours. Pursing of the net is slowed drastically or stopped completely. Canopy formation and/or net collapse may occur as a result of the delay if appropriate precautions are not

followed.

Sacking up: When the net has been rolled so that the fish are aggregated, a lifting process begins in which the net is pulled over the rail of the seiner. The net is made shallower by this process, and the fish are further confined and trussed up to the surface where brailing can begin. Normally an auxiliary winch and a choker winch are used to hold the load of the fish being sacked up.

Skiff: The skiff is an auxiliary boat carried on the stern of the seiner. It is generally 20-25 feet long and has a beam of 15-18 feet. The skiff is used in three essential components of the set: 1) It holds the bow ortza during the setting or laying out of the net, making it possible to retrieve both ends of the net after encirclement, 2) it is used with a tow rope (generally polypropylene) to pull on the seiner and optimize its position relative to the net, and 3) it is used to sack up the catch, providing necessary flotation for the catch and a platform for the brailing operation.

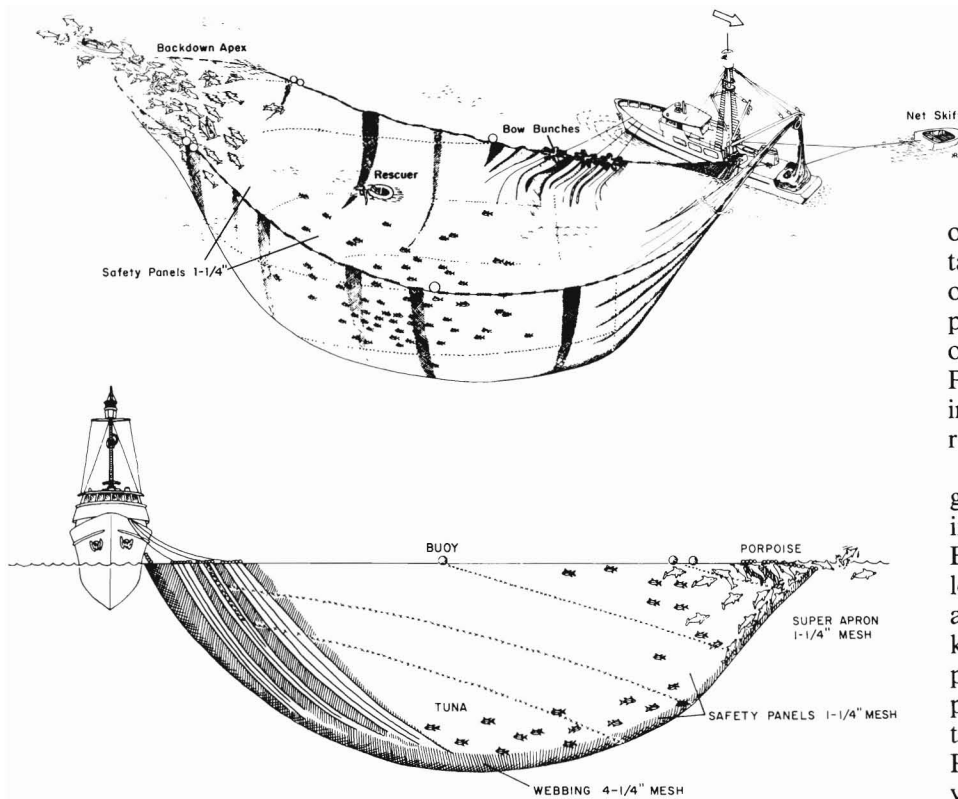
Speedboats: The speedboats carried on seiners are generally 16-18 feet long with a single seat. They are powered by 65-100 horsepower outboard motors and are designed for high-speed, open-ocean operation. Speedboats are used for many different processes in the set: 1) The chase and directing of the dolphin school prior to the set, 2) "patrolling" of the net after encirclement to keep dolphins away from hazard areas, 3) pulling on the net's reverse bunchlines or corkline to prevent collapse, 4) assisting in the process of pulling bow bunches by clearing the bunchlines and tangled corks, and 5) providing a platform for the hand release of dolphins throughout the set, but primarily during and after backdown. Tuna seiners usually use 4-5 speedboats in the course of a dolphin set.

Tie-down point: When a seiner prepares to back down, both ends of the net must be secured in order to withstand the resultant load. Canopy formation is minimized during backdown if the proper amount of net between the outermost bunch and the stern is left in the water. This optimal condition can be attained on every set if the tie-down points are marked. This can be done by painting the proper cork on the corkline (which is secured with the choker winch) and painting marks on the line controlling the outermost bow bunch.

Towline: The towline is attached to the stern ortza and permits retrieval of the ortza in sets where the circle described by the set has a longer circumference than the length of the net.

Winch: This refers to the large hydraulically operated main winch that is used to purse the net. It has three drums; one is used to retrieve towline, and the other two control the ends of the pursing cable.

Zipper: The zipper is a line (usually braided nylon) that runs through small rings which are tied to the net. One end is attached to the corkline at midnet. The other end is attached to the center of the chainline. When the rings have been loaded on the ring stripper, the chainline end of the zipper can be pulled. The midnet corks are pulled to the boat and the net is bisected on a vertical axis. The zipper is used to "cut" the net in sets where the catch is too large to sack up in one bunt without risking a rip and loss of fish. "Cutting" the net with the zipper makes it possible to sack up twice. After making the cut, the fish are divided into two sections of the net, each with a bunt. Part of the catch can be sacked up and brailed aboard from the midnet bunt. After these fish are loaded, this bunt is released. The remaining fish can be rolled to the main bunt and loaded in the normal manner.



Two views of typical purse seines during the backdown procedure.

of available research funds necessitated the concentration of resources on Phase-I activities. This situation persisted from 1970 through the end of fiscal 1977 when the beginnings of Phase-II research were incorporated into the existing mortality reduction research program.

In general, the NMFS research program has relied on several approaches in finding solutions to the problem. Enough detailed data had been collected by 1974 to allow a reasonably accurate evaluation of the causes of kill in nets. These data helped to pinpoint the major causes of kill so that potential solutions could be devised, tested, and transferred to the fleet. Particularly important in the early years (1970-74) was the search for effective net- and vessel-handling methods and gear refinements employed by a few captains and the dissemination of information on these methods to others in the tuna fleet. In the latter years of the program (1978-81), efforts to quantify and understand the basics of net behavior, especially during backdown (Coe and Sousa, 1972), led to further refinements in the backdown technique and the net design. Data on causes of kill, fleet performance, and net-handling techniques were gathered through both the voluntary observer program (1971-75) and the subsequent mandatory observer program (1976 through 1982) (NMFS, 1975). Experimental gear and methods were tested and modified at sea aboard tuna vessels, including a vessel that was donated by the tuna industry for 1 year (the 1978 "Dedicated Vessel" Program).

Table 2 lists all NMFS charter cruises which conducted mortality-reduction studies during the decade. Technology transfer and dissemination of information on improved mortality-reduction methods were accomplished through the observer program, formal presentations to industry groups, direct waterfront con-

been conducted. These guidelines specifically recognized the urgent need for research to develop gear and methods to reduce the incidental dolphin-kill rates.

The urgency of this research stemmed from two separate instances. First, biologists and government officials became concerned that the affected dolphin populations were being depleted by the apparent high kill rates. Second, the MMPA provided NMFS with the authority to severely curtail or even close down the U.S. tuna industry to prevent further killing of marine mammals. The Review Committee recognized that a possible result of curtailing or closing the U.S. tuna fishery would be the transfer of vessels to foreign registry. If this were to happen, there would be little likelihood of satisfactorily rectifying the tuna-porpoise problem. Therefore, the Committee recommended that the highest priority should be the development of fishing tactics and gear innovations that would not lessen the effectiveness of the current method of catching tuna. In addition,

the innovations would not be too costly and would ultimately permit the harvest of tuna without endangering the dolphin stocks. Through this approach, foreign fleets would adopt these economically feasible innovations, the U.S. tuna fisheries would be maintained, and realistic progress would be made toward marine mammal protection.

The Committee envisioned two mortality reduction research phases. Phase-I was the immediate development and transfer into practice of methods and gear to achieve the lowest possible dolphin kill rates using standard purse seining methods. Phase-II was the research and development of fishing systems that would allow the take of yellowfin tuna without capturing the associated dolphins. The Phase-II work was to be based on behavioral differences (natural or induced) between the tuna and dolphins and the design of compatible fishing systems to take advantage of those differences.

The need for immediate results in mortality reduction and the limitation

tacts, extension services to the fleet, distribution of published literature, and contact with the Industry's Expert Skippers' Panel (Federal Register, 1977). Regulatory and enforcement regimes established under the MMPA and managed by the NMFS Southwest Regional Office (beginning in 1976) also assisted in the incorporation within the fleet of a wide range of gear and procedures for mortality-reduction.

The total annual dolphin mortality in the U.S. fishery was estimated to be 315,000 in 1970 (footnote 2); by 1980 it had been reduced to an estimated 16,900³ (Allen and Goldsmith, 1982). These results stem not only from the application of research results, but also from extremely complex social, economic, and legal changes and processes affected through the efforts of many people in both the private and public sectors. In its direct research efforts on mortality-reduction methods and gear, NMFS alone has spent 2.4 million dollars, fielded 3,100 man-days at sea, and employed about 60 temporary and permanent employees. Because of the complex nature of the overall societal effort, the contribution of research to the reduction in total annual dolphin mortality is difficult to estimate.

The Nature of the Dolphin Problem

Operational Complexity.

Ten years of research have clearly shown that the problem of the incidental dolphin kill is multifaceted and not amenable to "key-discovery" solutions. Aside from occasional shark attacks and encounters with vessel power equipment (speedboats, powerblock, net skiff, brailer, etc.), death of dolphins by suffocation is the rule. Dolphins are killed when confined by the net in such a way that they are unable to rise to the surface to breathe. The animals are either entangled individually in the meshes or are entrapped singly or in groups by folds or "canopies" of net webbing. The probability that animals will

³Estimate includes 5 percent upward adjustment for seriously injured dolphins assumed to have died after release.

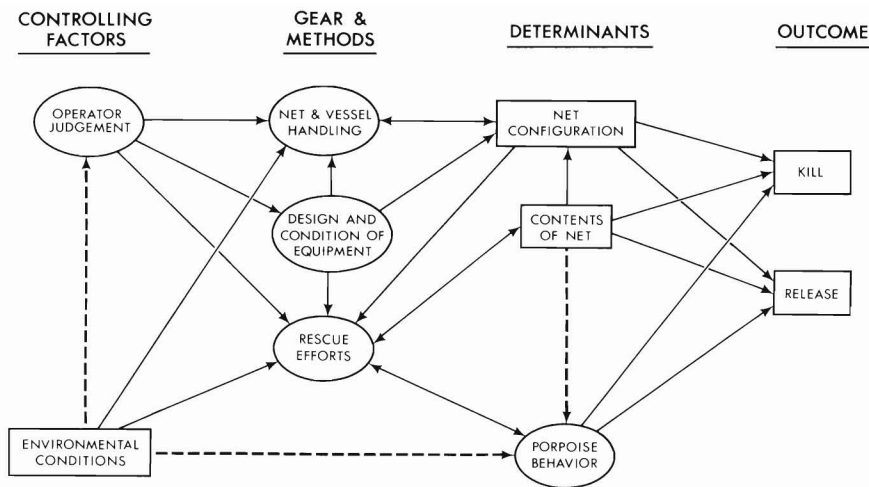


Figure 1. — A generalized schematic showing the operational interrelationships among factors controlling the use of gear and methods to influence the determinants of successful dolphin release from a tuna purse seine. Ovals indicate areas of NMFS applied research and education efforts. Broken lines between blocks indicate uncertainty in the nature of the relationship.

Table 2.—NMFS charter cruises with mortality reduction objectives.

NMFS cruise no.	Vessel	Dates	Cruise leader
	AVR <i>Miss Behavior</i> ¹	15 June -20 June 1970	W. F. Perrin
	RV <i>Cromwell</i> ¹	3 Sept. - 4 Sept. 1970	W. F. Perrin
	<i>Conquest</i>	21 Dec. -22 Dec. 1970	W. F. Perrin
11	<i>San Juan</i>	14 May -15 May 1971	W. F. Perrin
12	<i>Westport</i>	7 Sept. - 8 Sept. 1971	W. F. Perrin
13	<i>Queen Mary</i>	16 Nov. -17 Dec. 1971	W. E. Evans
26	<i>Independence</i>	27 Sept. -29 Oct. 1972	R. L. McNeely
27	<i>Independence</i>	11 Dec. -17 Dec. 1972	R. L. McNeely
28	<i>Independence</i>	1 Jan. -13 Feb. 1973	F. Wathne
51	<i>John F. Kennedy</i>	23 May - 5 June 1973	R. L. McNeely
52	<i>Trinidad</i>	16 Oct. -11 Nov. 1973	R. L. McNeely
53	<i>John F. Kennedy</i>	10 Nov. -15 Dec. 1973	J. Jurkovich
96	<i>South Pacific</i>	28 Oct. - 1 Dec. 1974	R. L. McNeely
97	<i>J. M. Martinac</i>	30 Oct. -21 Dec. 1974	D. J. Twohig
131	<i>South Pacific</i>	3 July -25 Aug. 1975	F. M. Ralston
132	<i>Bold Contender</i>	28 Sept. - 4 Dec. 1975	R. L. McNeely
133	<i>Eastern Pacific</i>	29 Sept. - 6 Dec. 1975	J. Jurkovich
207	<i>David Starr Jordan</i> ¹	5 Oct. -18 Nov. 1976	D. B. Holts
208	<i>Elizabeth C. J.</i>	11 Oct. - 9 Dec. 1976	W. F. Perrin, J. M. Coe
265	<i>Margaret L.</i>	19 May -11 Sept. 1977	R. W. McLain
328	<i>Margaret L.</i>	27 Oct. -22 Dec. 1977	J. M. Coe
329	<i>Maria Marie</i>	2 Nov. -25 Dec. 1977	C. B. Peters
375	<i>Queen Mary</i>	26 Jan. -16 March 1978	D. B. Holts
395	<i>Queen Mary</i>	17 Apr. - 5 June 1978	J. M. Coe
411	<i>Queen Mary</i>	22 June -18 Aug. 1978	F. T. Awbrey, D. A. Bratten
434	<i>Queen Mary</i>	12 Sept. -31 Oct. 1978	J. E. Powers
451	<i>Queen Mary</i>	11 Nov. - 9 Dec. 1978	D. B. Holts
517	<i>Cabrillo</i>	19 May -19 July 1979	G. L. Anderson
552	<i>Cabrillo</i>	18 Aug. - 7 Oct. 1979	M. Deerman
565	<i>Maria C. J.</i>	17 Sept. -22 Nov. 1979	J. M. Coe
658	<i>Maria C. J.</i>	22 Sept. -28 Dec. 1980	J. M. Coe

¹NMFS research vessel.

become entangled or entrapped depends upon the configuration of the net, the number of dolphins and amount of tuna captured in the net, the behavior of the captured dolphins, the skill of the vessel operator, and

the condition of the net and equipment.

Figure 1 is a simplified scheme showing the relationships between circumstances and processes which affect the kill and release of dolphins.

Almost every block in Figure 1 represents from three to several dozen components that interact within the block, and with many of the com-

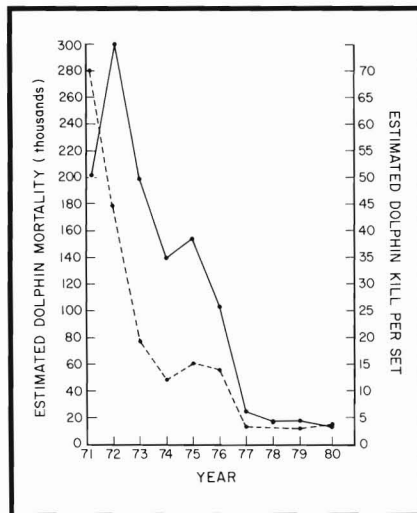


Figure 2.—Estimated annual dolphin mortality (solid line) and kill-per-set (broken line) by the U.S. tuna purse seine fleet.

ponents of the other blocks. Although a complete expansion of this diagram to show all of the known interactions at each level would yield a tangled mass of blocks and arrows, it would serve to illustrate the true complexity of the problem and the degree of skill and attention required of an operator to successfully negotiate sets on dolphins day after day. The estimated annual mortality figures shown in Figure 2 and Table 3 illustrate the effectiveness of the U.S. regulations on gear and methods imposed on operators in 1976, 1977, and 1978, and demonstrate the operators' ability and willingness to incorporate the regulations into their operations. Table 4 indicates a general decrease in the percentage of disaster sets—sets in which a kill of 16 or more dolphins occurred. One would expect to see occasional sets with high kills even from captains with otherwise excellent performance records since environmental conditions, most dolphin behavior, and certain equipment failures cannot be controlled. The number of disaster

sets fell to less than 3 percent of all observed sets in 1980. Under the present level of technology, further significant reductions in this percentage appear remote.

Pinpointing Causes of Kill

The essential information on specific causes of dolphin mortality and the magnitude of the contribution of each cause was gathered in a variety of ways. In the early years of the program, research directions were based primarily on the field observations of the sea-going staff and on reports from vessel captains. Much of this information was never recorded except in the minds of the researchers because the urgency of the work precluded preparation of lengthy official documents and reports. As the sophistication of the whole "tuna-porpoise" program increased, placing observer records into computers made it possible to store and recover more data related to causes of mortality and fleet performance. Since 1976-77, this data-management capability has

Table 3.—Summary statistics of dolphin sets from NMFS observer trips, 1971-80. Numbers in parentheses are sample sizes.

Statistic	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1. Total number of dolphin sets	51	273	705	993	948	754	3,408	1,811	2,036	1,007
2. Number of pure spotted-dolphin sets	23	117	302	425	361	255	1,093	931	1,015	587
3. Number of pure spinner-dolphin sets	0	0	17	15	11	9	14	8	7	6
4. Number of mixed spotted and spinner sets	25	132	279	365	412	399	756	680	503	257
5. Number of common-dolphin sets	2	23	105	142	96	55	10	4	7	1
6. Number of others and unidentified dolphin sets	1	1	2	46	68	36	1,535	188	504	156
7. Average tons of yellowfin per set	18(48)	20(272)	14(705)	11(993)	13(948)	13(754)	12(3,408)	11(1,811)	11(2,035)	10(1,006)
8. Average number of dolphins caught per set	219(48)	486(245)	378(705)	355(980)	634(947)	816(720)	813(3,107)	821(1,612)	658(1,797)	643(905)
9. Average dolphin school size per set ¹	298(48)	1,007(239)	907(703)	1,163(866)	1,216(945)	1,419(734)	1,656(3,205)	1,446(1,669)	1,170(1,870)	1,054(935)
10. Average dolphin kill per set	70(48)	43(272)	19(705)	12(993)	16(947)	14(754)	3(3,408)	4(1,809)	3(2,034)	4(1,006)
11. Average dolphin kill per ton of yellowfin tuna	3.8	2.2	1.3	1.1	1.3	1.1(754)	0.2(3,408)	0.4(1,809)	0.2(2,033)	0.3(1,006)
12. Percent dolphins killed of dolphins caught	31.9	8.9	4.9	3.4	2.5	1.8(720)	0.4(3,107)	0.5(1,611)	0.3(1,797)	1.6(904)
13. Percent of school captured ¹	73.5	48.3	41.7	30.5	52.2	57.4(719)	49.6(2,984)	57.5(1,540)	58.3(1,730)	63.1(885)
14. Percent of school killed ¹	23.5	4.3	2.1	1.0	1.3	1.0(734)	0.2(3,205)	0.3(1,667)	0.2(1,868)	0.4(934)
15. Percent of sets catching yellowfin tuna	92(48)	89(273)	82(705)	74(993)	82(948)	83.3(754)	84.7(3,408)	85.3(1,811)	87.3(2,035)	91.3(1,006)
16. Percent of sets catching dolphins	100(48)	91(273)	86(705)	83(993)	91(947)	91.4(720)	95.5(3,107)	97.4(1,612)	97.2(1,797)	99.3(905)
17. Percent of sets catching dolphins with zero killed	2(48)	12(248)	18(601)	22(827)	24(863)	30.4(658)	56.5(2,968)	58.4(1,569)	71.4(1,746)	67.5(898)

¹Estimates generally have a low precision.

Table 4.—Summary statistics of sets with dolphin kill greater than 16, from NMFS-observed trips. Number of dolphins killed.

Year	Number of sets (%)	Total kill	Backdown canopies				Pre-B.D. net collapse	B.D. channel collapse	Malfunction mortalities	All other causes	Unknown
			Bow	Stern	Other	Total					
1977	135(4.0)	5,277	749	1,539	774	3,062	440	346	329	339	780
1978	73(4.6)	4,932	478	486	872	1,836	1,897	338	397	243	221
1979	54(3.5)	2,879	960	173	43	1,176	284	326	84	925	84
1980	30(2.9)	2,647	106	206	220	532	29	1,504	303	140	139
Total	292(3.9)	15,735	2,293	2,404	1,909	6,606	2,650	2,514	1,113	1,647	1,224
Percent of total kill		100	15	15	12	42	17	16	7	10	8

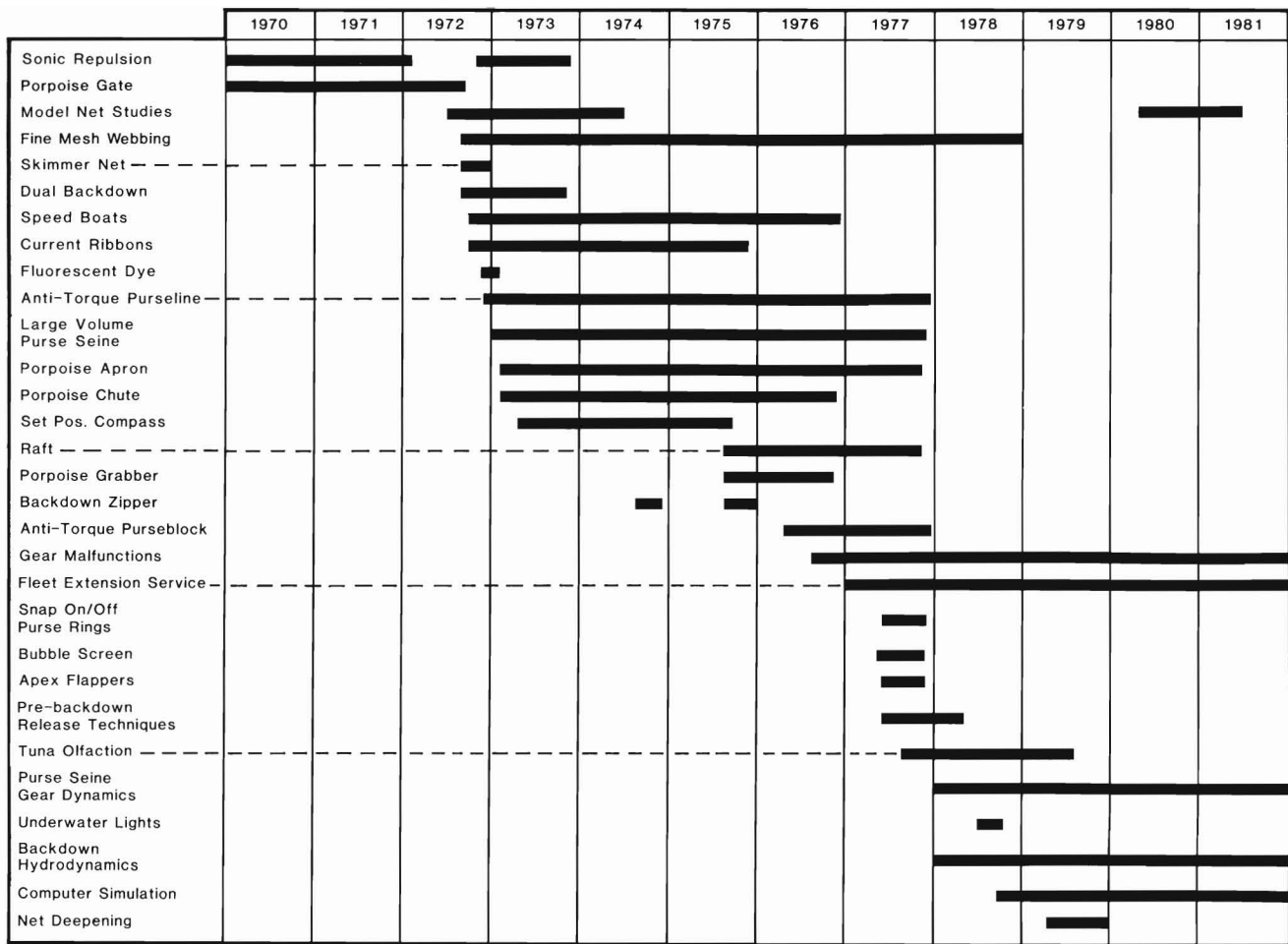


Figure 3. — Areas of NMFS dolphin mortality reduction research since 1970, by subject areas.

allowed analyses that assess the performance of experimental gear and techniques and that allow tracking of the major causes of dolphin kill. Table 4 shows the primary causes of kill for disaster sets from 1977 through 1980. The primary causes are related to net configuration (i.e., backdown canopies, prebackdown net collapse, backdown channel collapse). Most of the malfunction-related kill is also due to resultant net-configuration problems. An example of an "other" cause of mortality is when the dolphins are "sacked-up" in the bunt with the tuna and suffocated. The unknown causes of kill are, for the most part, related to the

behavior of the captured dolphins.

Specific Research Efforts

Shown in Figure 1 are the areas in which NMFS has focused its research. Net and vessel handling, so as to minimize net-configuration problems, was of primary importance along with the development and improvement of effective rescue and release techniques. Some effort has gone into the search for methods of eliciting differential responses of tuna and dolphins that could be employed in separating them before or during a set. In this section, the specific areas of research are discussed. They have been categorized according to the

functional areas presented in Figure 1. There is a significant overlap among these categories because of the multidimensional nature of the problem. Research projects that apply to two or more categories are grouped into the category most closely related to the original intent of the project. Figure 3 lists the specific areas of research chronologically and shows their approximate duration during the NMFS mortality-reduction program.

Net and Vessel Handling

Table 4 indicates that net configuration has a major influence on dolphin mortality. Chief among the various configuration problems is

prebackdown net collapse, which can be caused by strong currents, changes in wind direction and strength, major equipment malfunction, failure of the captain to orient the set properly with the wind, or any combination of these problems. Regardless of the cause of prebackdown net collapse, the outcome is the same; that is, a substantial portion of the captured dolphin school will be killed and the tuna may be lost as well. Because the fishery will, at times, involve setting despite adverse conditions and because equipment may occasionally fail, the development of a means to prevent net collapse rather than remove the causes was essential.

Speedboats to Prevent Net Collapse

Beginning in late 1972, experiments on the use of speedboats to prevent net collapse were initiated. Since most tuna seiners carried four or five speedboats for herding dolphins, the means for towing on the net were readily available. During the chartered cruises of the M/V *Trinidad* (1973), the M/V *John F. Kennedy* (1973), the M/V *South Pacific* (1974), and the M/V *Bold Contender* (1975), the methods and the practicability of using up to three speedboats to tow on the net to prevent net collapse under most conditions were proven^{4,5}.

Tests during commercial fishing operations showed that the temporary crew reduction on deck while speedboats were towing did not cause a marked increase in the duration of the set, especially when the alternative of dealing with large numbers of dead dolphins was considered. However, to avoid reducing the deck crew during a set, most captains became more attentive to their methods of setting in order to reduce the likelihood of net collapse. A substantial portion of the reduction in observed kill-per-set was

due to increased awareness on the part of the captains. The 1976 regulations required at least two speedboats to be in the water during every set on dolphins and that they be crewed and prepared to tow on the net should it be necessary before the start of backdown. Since the need to tow on the net to prevent imminent collapse was infrequent if captains were careful, this regulation was considered a nuisance and was ignored by many captains.

Optimizing Set Orientation

While the use of speedboats was being developed, devices to provide more information to the captain on the direction of the current and the orientation of the set relative to the wind and current were examined. With this information, the captain could select the optimal set orientation to minimize the potential for net collapse. A current-direction indicator consisting of a roll of approximately 100 m of surveyor's tape with a weight on one end and a float on the other was tested on the cruises of the M/V *John F. Kennedy* (1973), the M/V *Trinidad* (1973), the M/V *J. M. Martinac* (1974), the M/V *South Pacific* (1974), and the M/V *Bold Contender* (1975).

Concurrently, a multibezel compass was devised that allowed the captain to set the bezels for wind and current direction (from the current-direction indicator) and to determine the direction in which to initiate the set that best balanced those forces on the net. The current indicators were found to be unreliable because they only indicated surface-current direction while it is the difference in magnitude and direction of surface and subsurface currents that affects the net.

The multibezel compass provided the correct information to properly orient a set. However, the business of orchestrating the chase and controlling the activities on board the seiners generally kept captains too busy to use this tool. Since the current indicators were not always reliable, and the multibezel compass only showed the correct orientation to the wind, which was available to the captain from direct observation, there was no

need for the compass. This line of experimentation was therefore dropped.

Preventing Roll-ups

Most purse seine sets are not likely to result in a collapsed net if the net is retrieved without much delay. A common delay in purse seining is the roll-up in which the purse cable, leadline, and webbing become wrapped around one another, usually in both directions of rotation, such that they lock against each other. When a severe roll-up occurs, the net cannot be pursed until the roll-up is cleared. The delay can result in net collapse if speedboats are not used to hold the net open.

NMFS began studying the cause of roll-ups in late 1972 and discovered that roll-ups are caused by the purse cable rotating as tension is increased or decreased. Standard wire rope used for purselines is analogous to a long spring that, when stretched, creates torque along its length. When tension is applied, the cable rotates in one direction, and when tension is relieved, the cable rotates in the opposite direction. If, when setting the net, the leadline or webbing comes into contact with the rotating purse cable and is snagged, a roll-up results. Roll-ups occur occasionally on every vessel in the fleet.

In 1973, antitorque purselines were constructed and tested on chartered cruises of the M/V *John F. Kennedy* and the M/V *Trinidad*. These purselines were constructed of torque-balanced wire rope, which allows virtually no tension-induced rotation to occur because of the opposing lay of its major and minor component strands. The tests showed that the antitorque purseline worked. Beginning in 1974, NMFS supplied the cable to vessels that were experiencing a high frequency of roll-up sets. Roll-ups, however, still occurred on these vessels but less frequently. The fishermen also encountered a problem with the press fittings used to form eyes at the end of the cable. When the press fittings passed over the purse blocks they eventually cracked and required repair. A special splicing technique to form the eyes was developed. However, the fishermen did not completely accept this remedy, and by

⁴Everett, J., J. E. Powers, R. McNeely, J. M. Coe, and R. Butler. 1976. The use of speedboats in reducing incidental porpoise mortality in tuna purse seining. U.S. Dep. Commer., NOAA, NMFS, SWFC Admin. Rep. LJ-76-35, La Jolla, Calif., 29 p.

⁵McNeely, R. L., and D. B. Holts. 1977. Methods of reducing porpoise mortality in the yellowfin purse seine fishery. U.S. Dep. Commer., NOAA, NMFS, SWFC Admin. Rep. LJ-77-13, La Jolla, Calif., 19 p.

1976 most of the vessels that were experimenting with antitorque purselines replaced them with conventional purselines.

That roll-ups still occurred with the antitorque purseline indicates that the cable is not rotation free. The torque-balanced cable has a much longer, more open lay than conventional cable, and when passed over standard purse blocks under tension it has a tendency to flatten out. This "unlaying" of antitorque cable on the sheave of the purse blocks artificially induces torque (and rotation) into the purselines. To correct this problem, special purse blocks were designed with a 20-inch pitch diameter that were counterbalanced so the cable would always ride in the center of the sheave and not flatten out. A system of antitorque purseline and counterbalanced purse block was tested during three cruises aboard one of the more roll-up prone seiners. The results were inconclusive^{6,7} and the research was terminated. To date, the antitorque system has not been further developed or incorporated into the fleet.

Quick Release Purse Rings

To remove and reattach purse rings easily during pursing has potential for increasing the speed with which the net can be retrieved when a malfunction occurs. A fisherman, Raphael Guillen, invented a snap link for this purpose in 1976. The NMFS tested this device during the chartered cruise of the M/V *Margaret L.* in 1977. The snap links were found to be useful in reducing delays in net retrieval and the device was recommended to the fleet.

Optimizing the Backdown-Channel Configuration

The most delicate and also most important net- and vessel-handling technique in a purse seine operation involving dolphins is backdown. A

large part of the dolphin mortality occurs during backdown (Table 4). By the end of 1977, considerable progress had been made in solving the problem of prebackdown net collapse, and biologists had begun to understand the dynamic processes governing breakdown-related dolphin mortality.

A diving program was established, a model-net study program was initiated, and instruments for recording depth, depth/time relationships, net and vessel speed differentials, and relative changes in enclosed surface area were assembled. Cruises of the M/V *Queen Mary* in 1978 and the M/V *Maria C.J.* in 1979 and 1980 were designed to collect information on net behavior during breakdown. Observations from those cruises resulted in recommendations for an improved mid-net zipper design (Holts, 1980), more precise net tie-down locations on the net for optimal backdown-channel configuration, and instructions for determining causes and remedies for poor backdown performance (Coe et al., In press). This work also served to identify some previously unknown features of backdown dynamics.

Net-Depth Effects

With the development of improved methods for assessing the physical performance of a purse seine, efforts to quantify and demonstrate the positive effects of increased net depth were carried out. With bathymographs and a systematic method for approximating net-enclosed surface area, an experiment was run aboard the M/V *Cabrillo* in 1979. For the experiment, the *Cabrillo's* net was deepened by two standard strips tapered at each end and inserted at the leadline. The average fishing depth of the net was increased by 17.3 m (9.4 fm) using six bales⁸ of webbing. Net-enclosed surface area was increased by an average of 11.5 percent which gave the dolphins more room to move both before and during backdown. This also increased the time for the net to collapse. As a result of this experiment, specific performance data were collected to support the long-

standing NMFS recommendation (footnote 5) that nets used on dolphin schools should be deepened whenever possible.

Miscellaneous Techniques

Many simple methods of employing standard vessel- and net-handling gear to minimize net configuration problems were recorded and shared with captains in the fleet. Most of these methods were obvious and effective but were not necessarily widely known. For example, in a normal set the captain has at his disposal the use of the net skiff, the bowthruster, and the main engine to prevent net collapse and to position the vessel in order to effect a smooth transition into backdown. Coe et al. (In press) discussed these techniques in detail.

Dolphin Handling Methods and Gear

While research on net- and vessel-handling techniques sought to prevent situations that directly endangered dolphins confined in the net, research on dolphin handling methods and gear sought ways to release dolphins efficiently from the net. Again, many of the effective methods for dolphin handling were practiced by the fishermen before this research program was begun, though many either were not widely used or were not being employed to their maximum effectiveness. Obvious examples are the backdown maneuver and the Medina Panel (see Glossary: Table 1).

Alternatives to Backdown

One of the earliest and most commonly suggested solutions to the tuna-porpoise problem was a gate built into the net that could be opened to allow the dolphins to swim away. A porpoise gate was built and tested aboard NMFS research vessels in 1970 and the M/V *Westport* and M/V *San Juan* in 1971. The gate (an inflatable/deflatable tube replacing a section of corkline) performed as designed. It sank rapidly to provide a controllable 15 m wide by 4.5 m deep opening. The dolphins, however, would not take advantage of the opening despite being herded with skiffs and a false corkline with evenly

⁶Coe, J. M., and D. A. Bratten. 1978. Cruise Report: M/V *Margaret L.*, October 27-December 22, 1977. NMFS Southwest Fish. Cent., La Jolla, Calif. Unpubl. rep., 9 p.

⁷McLain, R. W., D. A. Bratten, and J. M. Coe. 1977. Cruise Report: M/V *Margaret L.*, May 19 to Sept. 11, 1977. NMFS Southwest Fish. Cent., La Jolla, Calif., Unpubl. rep., 8 p.

⁸100 meshes deep × 100 fathoms long, stretched mesh.

spaced drop lines. White noise (randomly generated sounds of equal energy) and killer-whale sounds were also used to herd the dolphins to the opening without success. These results illustrated a fundamental behavior of dolphins: The dolphins are more afraid of the net than of anything within it. To release them from the net requires some active process that literally pulls the net out from under them. Although this principle was recognized early on, several alternative methods for release were also considered in the early and mid 1970's.

Dual Purselines

The first alternative method was based on the hypothesis that early in a set there is a distinct vertical separation of tuna and dolphins (the dolphins at or near the surface and the tuna well beneath). It was proposed that a secondary purseline be installed at mid-depth, running the length of the net, that could be pulled at the same time as the standard purseline. Thus the pursed net would be divided into upper (dolphins) and lower (tuna) compartments (footnote 2). The corkline could then be opened with a zipper arrangement, and the dolphins either would swim out or be forced out by pulling the net from under them. A model net was built in mid-1972 to test the mechanics of this concept. However, further work on this was abandoned when underwater observations made aboard the M/V *Independence* in late 1972 showed that there was no consistent spatial or temporal separation of tuna from dolphins in the net.

Skimmer Net

In late 1972 the idea of using a lampara-type skimmer net was tested to see if the dolphins could be quickly gathered together and dumped over the corkline soon after pursing was completed. The M/V *Independence* was chartered for tests off southern California. The tests showed that the concept did not work because: 1) Most of the dolphins easily avoided the skimmer net, 2) dolphins that were herded to the corkline were trapped there and could not be easily released, and 3) speedboats did not

have enough power to pull the skimmer net effectively.

The Dual Backdown

NMFS observations indicated that a number of dolphins were often left alive in the net after backdown. Afraid of losing the tuna, the captains discontinued backdown before all the dolphins were released. As a possible solution to this problem, a dual backdown system was conceived in 1973 and tested using model nets aboard a chartered salmon seiner and the tuna seiners M/V *John F. Kennedy* (May 1973) and M/V *Trinidad* (October 1973).

The dual backdown principle involved the development of a net configuration with two backdown channels of approximately equal size adjacent to each other, with a controllable passage between them. Tuna normally cruise up and back in the channel during backdown, so that they might be directed through a passage into the second channel and held there without risk of escape while all of the dolphins were released from the first channel. In practice, the dual channels were difficult to form without collapsing them, and the tuna were never effectively transferred to the second channel. The idea was therefore abandoned as impractical.

Small Mesh Safety Panels

Harold Medina observed that the standard mesh size (4¼-inch stretched mesh) for tuna seines was much too large to prevent the entanglement of dolphin snouts and flippers. In 1970 he installed a strip of 2-inch stretched mesh webbing at the backdown apex of his net and noted good results. Data collected by NMFS observers in 1971 and 1972 (footnote 2) from vessels with and without the 2-inch panel confirmed Medina's results, showing lower mortality rates for vessels with the smaller mesh panel. A great deal of subsequent industry and NMFS research effort from 1972 through 1977 went into extending Medina's concept and developing better safety panels for the backdown channel, since backdown literally forces the dolphins into contact with the net while effecting their release.

The single-strip, 2-inch mesh

Medina Panel was rapidly incorporated into nets of the U.S. fleet, and by 1974 nearly all nets had it. Some captains chose to use two strips of 2-inch mesh of varying lengths for their backdown apex. In 1973 experts questioned whether the 2-inch mesh was the ideal size to prevent entanglement. NMFS conducted a series of experiments to determine the mesh size that was most effective in preventing entanglement of beaks and flippers (Barham et al., 1977) and found that 1¼-inch stretched mesh was most appropriate. Accumulated observations of where dolphins became entangled in the channel were used to establish NMFS specifications for the placement of 1¼-inch mesh safety panels, which replaced the 2-inch mesh Medina Panels.

In 1973, NMFS designed and built a large volume net that was 17 strips deep. The net's backdown area was protected by a safety panel that was made up of three standard-depth strips of 1½-inch stretched mesh webbing. The large-volume net was tested on cruises in late 1973 (M/V *John F. Kennedy*) and 1975 (M/V *South Pacific*) with encouraging results. Further refinements in safety-panel design were investigated during the 1976 fishing season, when 20 volunteer vessels were equipped with 1¼-inch mesh safety panels either with or without an apron-chute appendage (see below). The kill rate for these vessels were markedly lower than those for vessels with a regular net⁹. In 1977, all vessels were required to install two strips, each 340 meshes deep, of 1¼-inch mesh webbing 180 fathoms in length, starting within the second outermost bow-corkline bunch and running sternward. The industry accepted this modification as a progressive change, and, although there were some webbing supply problems, most vessels were in compliance by the end of 1977. The reduction in kill rate from 14 animals per set in 1976 to 3 animals per set in 1977

⁹Coe, J. M., and J. DeBeer. 1977. Results of the 1976 twenty-vessel test of two fine mesh systems to reduce incidental porpoise mortality in tuna purse seining. Unpubl. manusc. on file at NMFS Southwest Fish. Cent., La Jolla, Calif., 75 p.

(Table 3) was, in our view, largely the result of this change in net design.

Preventing Backdown Canopies

While collecting data on the backdown procedure, biologists observed that net canopies made dolphin release more difficult and contributed to dolphin mortality. Surface net canopies entrap dolphins and prevent them from drifting or swimming to the apex of the backdown channel to be released from the net. Because of the canopies, up to 20 animals were occasionally left in the net after backdown.

To eliminate surface canopies, the slack webbing near the surface of the backdown channel needs to be redistributed to optimize the amount of net in the water. In the fall of 1974 a tapered, trapezoidally-shaped section of 2-inch mesh webbing called the "apron" was installed in the net of the chartered vessel *M/V South Pacific*. The apron was inserted between the corkline and the upper edge of the safety panel, with its short side up, and centered at the backdown apex. This installation required tie-down to be at the same place for each set. On this cruise, the apron was tested and judged effective in reducing surface canopies in the backdown channel.

A number of vessels volunteered to test aprons during the 1975 fishing season and had mixed results and opinions¹⁰. A similar 1¼-inch mesh apron with a more sharply tapered extension piece mounted at its top center (called the "chute") was installed with a 1¼-inch mesh safety panel in the net of the *M/V Bold Contender* in the fall of 1975. Results with this net design were extremely encouraging, producing kill rates well below the 1975 fleet average. The "Bold Contender System," as the apron-chute complex came to be known, was tested on 10 vessels and compared with 10 vessels using only the two-strip, 1¼-inch mesh safety panel. This test ran the entire year of 1976.

When the results were analyzed, both systems were found to produce significantly lower kill rates than did conventional gear, with the Bold Contender System slightly better than the safety panel alone (footnote 9 and SWFC¹¹).

During this 20-vessel test, some simple problems in handling the Bold Contender System were identified. To deal with these problems, the chute was trimmed down so that the remaining "super apron" was a long, low triangle with its apex coinciding with the desired backdown channel apex. This modification seemed to eliminate the handling problems. The net design was adopted voluntarily by a number of vessels in the fleet, based on the results of the fall 1976 chartered cruise of the *M/V Elizabeth C. J.* The super apron became mandatory by regulation beginning in 1978.

The Backdown Zipper System

At the same time that the apron was developed, biologists designed a method to reduce the risk of loss of tuna during backdown. A series of 3-inch steel rings were lashed to the net in the backdown area in a way that allowed a rope to be strung through them. The rope, when pulled, pinched the channel shut near the apex. The idea was to back down until all the dolphins were at the apex and the tuna had moved toward the boat, and then to pull this backdown zipper separating the dolphins and tuna.

During the charters of the *M/V South Pacific* (1974) and the *M/V Bold Contender* (1975), the mechanics of the zipper proved sound, but the dolphins were not always on the apex side. In addition, the zipping action caused the apex end of the backdown channel to become shallow and to collapse. The animals became entrapped and were not easily released. The zipper idea was therefore rejected. As an alternative, the apron was refined so that it produced a sloping apex floor

that tended to turn the fish away from the release area and thereby reduce the loss of fish during backdown.

Releasing Dolphins by Hand

In considering ways to increase the number of sets with no dolphins killed, it was recognized that backdown alone rarely got every animal out of the net and that some efficient form of hand-release of individual animals was needed. Several rescue techniques for hand-release were already in use in the fleet prior to NMFS involvement. These were: 1) Rescuers in speedboats released animals at the surface and next to the corkline, 2) rescuers dove and swam in the net to catch and release both entangled and free-swimming dolphins, and 3) from the speedboats and the net skiff, rescuers used gaffs to guide dolphins over the corkline. Rescue from speedboats was inefficient because of the rescuers' limited reach and lack of mobility. Swimming in the net was fairly efficient, depending on the skills of the rescuer, but dangerous because of potential shark attacks and rescuer entanglement in the net. Gaff wounds are potentially fatal to dolphins, depending on the severity and location of the punctures.

During a cruise aboard the *M/V Gina Karen* in 1974, it was noted that having two persons aboard a speedboat stationed at the backdown apex during backdown increased efficiency of hand-release of dolphins. Analyses of data from the fleet supported this conclusion, and the practice was made a requirement in 1975. During the charter cruises of the *M/V Bold Contender*, the *M/V Elizabeth C. J.*, and the *M/V Margaret L.*, NMFS tested the feasibility of using an inflatable one- or two-man raft as a platform from which rescue could be performed. It was found that, with practice, a single man in the raft could easily maneuver the raft and, with the aid of a face mask and snorkel, rescue dolphins more efficiently than any other method. Furthermore, the raft provided some protection for the rescuer from shark attacks, while the face mask allowed him to see clearly whether there were sharks, billfish, stingrays, or jellyfish in the area where he was working. This raft-

¹⁰Coe, J. M. 1976. The effectiveness of the porpoise apron in improving the backdown procedure. U.S. Dep. Commer., NOAA, NMFS, SWFC Admin. Rep. LJ-76-38, La Jolla, Calif., 17 p.

¹¹SWFC. 1972. Unpubl. manusc. by SWFC Staff on file at Southwest Fish. Cent., La Jolla, Calif.

rescue technique has been in use by the fleet since 1976. Since hand-release in any form is not without some risk, the regulation is written so that raft use is at the captain's discretion.

While the raft-rescue technique was being tested on the M/V *Bold Contender* and M/V *Elizabeth C. J.*, some dolphins were observed to drop out of the school at the surface and come to rest passively on the floor of the backdown channel for a few minutes before rejoining the school. Without a mask and snorkel, the rescuers were not able to see these passive animals. The animals the rescuers did see were presumed dead. Passive behavior (Coe and Stuntz, 1980) was largely responsible for the unexpected appearance of live dolphins in the net after what had seemed to be a completely successful backdown with all dolphins released. The raft rescuer with a mask and snorkel can see the passive dolphins, signal the captain to continue backdown, and rescue the dolphins as they come to the surface. A regulation requiring the raft rescuer to wear a mask and snorkel also required backdown to continue until all live dolphins were released from the net. We believe that this regulation has contributed to the increased frequency of zero-kill sets after 1976 (Table 3) and the overall reduction in dolphin mortality.

Regulations in 1976 made the use of gaffs or other sharp-pointed instruments on dolphins illegal. When direct hand-release was not feasible (e.g., during sacking-up, after backdown, in the presence of sharks) a long-handled instrument (shepherd crook) for moving and controlling dolphins was needed and NMFS designed, built and distributed a number of different types of shepherd's crooks between 1975 and 1977. Results and opinions varied considerably among the users, but it was clear that in many circumstances the crooks could be effective and the degree of effectiveness depended on the user's effort. Many vessels have carried and made use of the devices.

The Apex Flapper

Behavioral observations made during the development of the raft rescue technique led to studies on altering the structure of the backdown apex to make it easier for the dolphins to leave the net. During backdown, many dolphins come into contact with the net just below the corkline and either swim back into the channel or lie against the webbing and are carried with it. Also, when tuna approach the backdown apex they see the webbing and corkline and usually turn back into the net, even though the corkline may be 3 or 4 feet underwater. It was reasoned that if the apex could be made semipermeable to dolphins and still present a visual barrier to the tuna, a more efficient backdown might result.

The initial and only attempt to design a differentially permeable apex produced the apex flapper system, which consisted of overlapping trapezoidal pieces of 1¼-inch mesh of increasing height placed above the corkline and centered at the backdown apex. A flat spot of about 20 fathoms was cut at the top of the apron (at the backdown apex), most of the floats were removed from the corkline, and the flappers, with floats attached at the top and middle, were laced in along the apex flat spot. This modified apron was tested on the M/V *Margaret L.* in the fall of 1977. Tests showed that too much flotation was left at the corkline, so the flappers tended to float on the surface inhibiting release and rescue at all but the highest backdown speeds. The merits of the apex flapper concept were never fully assessed and the method has not come into use.

The Downhaul Gate

Aboard the first cruise of the dedicated vessel M/V *Queen Mary* in 1978 (DeBeer et al.¹²), a simple

¹²DeBeer, J., F. Awbrey, D. Holts, and P. Patterson. 1978. Research related to the tuna-porpoise problem: Summary of research results from the first cruise of the dedicated vessel, January 26 to March 16, 1978. U.S. Dep. Commer., NOAA, NMFS, SWFC Admin. Rep. LJ-78-14, La Jolla, Calif., 27 p.

system of downhauls in the half-net area that could be adjusted in length to cause the corkline to sink during pursing was rigged for testing. The intent was to create an opening through which dolphins could be driven before the purse rings were brought on board using the downward force on the corkline exerted by the purse winch. Before the test could be conducted, however, the downhaul ropes became tangled in the corkline during setting, and had to be removed.

Other Modifications

A number of additional minor dolphin-rescue modifications pursued during the decade deserve brief mention. During the chartered cruises of the M/V *J. M. Martinac* (1974) and the M/V *South Pacific* (1974), the effectiveness of closing the hand-hold openings and corkline hangings to prevent entry of dolphin beaks and flippers was shown. Regulations to implement this finding were enacted in 1976. Experiments to determine the efficiency of large safety panels and aprons on the smaller vessels in the fleet were run on the M/V *Eastern Pacific* (1975) and the M/V *Marla Marie* (1977) with mixed results.

Evaluating Integrated Net Designs

The means for testing and demonstrating the gear ideas developed by the project ordinarily consisted of simple vessel cruises employing their own net with a specific modification. The high cost of dedicated vessel time and net construction and maintenance prohibited the integration and testing of broad combinations of experimental gear. However, three methods were developed to evaluate multiobjective gear designs: 1) A full-sized net, 2) scale-model nets, and 3) an interactive computer simulation of net behavior.

Large-Volume Net

In the summer of 1973, this prototype net was designed to demonstrate a number of advanced dolphin-saving features as well as advanced fishing

technology. Its decreased length:depth ratio and sharply tapered ends increased the enclosed surface area (and volume) when pursed, reducing the probability of net collapse. It was the first net to have three strips of dolphin-safety panel of less than 2-inch mesh (today's nets with aprons effectively have 3 $\frac{1}{3}$ -strip safety panels of 1 $\frac{1}{4}$ -inch mesh). It was also the first net to have handholds and corkline hangings laced shut in the backdown area to prevent entanglement. Lighter than normal twine was employed in the body of the net, which saved material costs and let the net sink and be pursed more rapidly (an idea that has recently been employed by the fleet). Its depth of 17 strips of webbing was 5 or 6 strips deeper than most nets in the fleet at that time (today 15- or 16-strip nets are quite common). Its advanced designs have only recently gained wide acceptance. By 1975 the cost of maintenance and repair of this net was too high and the project was transferred to another Federal agency.

Scale Models

Two scaled-down model nets were built early in the program to study radical changes in fishing procedures and net designs. The first model was a 1:25 scale model of a nine-strip deep net which had a midnet purse line running the entire length. It was used to test the feasibility of double pursing to separate the tuna from the dolphins. These tests showed the concept to be unpractical, saving considerable time and resources in the early period of the program.

A second 1:50 scale model of a newly designed purse seine was constructed in the spring of 1973. This model featured 1) 17 strips to provide greater surface area thus preventing net collapse, and 2) tapered ends to reduce excess webbing and attendant gear malfunctions. This model showed sufficient promise and a full-sized, 17 strip, purse seine (the Large-Volume Net) was built in the fall of that year.

These early tests provided valuable information on purse seine dynamics and were useful in focusing research effort and resources on specific problem areas. They were again used in 1980 (Holts and Coe, 1982) to study the dynamics of both normal and modified backdown procedures as well as various related gear malfunctions.

Computer Simulation Model

There are two principal methods of determining net behavior: Experimental and analytical. The experimental method has the overwhelming advantage of producing tangible and irrefutable results. The disadvantages of the method are numerous: The expense of chartering fishing vessels is great, ocean parameters cannot be controlled and are difficult to measure, and modifying nets is costly.

In direct opposition, the analytical method has the disadvantage that the results are not real and may be challenged. This disadvantage can be eliminated by comparing the results of analysis with experimental measurements. If the analysis is verified by this comparison, the advantages of the second method are realized: Low cost and control of the ocean and net parameters. The key to obtaining these advantages is experimental verification.

From 1978 to 1981 a substantial portion of the funds for the mortality reduction project was spent to research and develop a computer-based, interactive numerical simulation of purse seine behavior and to establish field measurements with which to verify the results of the simulation program. Basic performance parameters such as sinking rates, pursing speed and tension, enclosed area and volume, setting speed, retrieval speed and backdown forces, and net skiff towing force were measured on the dedicated vessel (1978) and charters of the M/V *Maria C. J.* (1979 and 1980).

The computer simulation was developed in three phases under contract and was nearing completion in the fall of 1981. The simulation pro-

gram was based on a system of differential equations which describe the motion of the net to be simulated. The user defines a sequence of external events (water currents, setting, pursing, etc.) affecting the motion which is to be simulated. The product of a simulation consists of a binary file for graphics display. Ultimately, the simulation was intended to be a broadly flexible tool for computer aided design (CAD) for a variety of fishing systems. This flexibility and accuracy were essential for cost-effective development of fishing systems directed to Phase-I goals. This program was terminated before benchmark runs could be carried out and simulation limits verified. Although the model was not used to solve fishing gear problems, it was used to simulate towed cables (Delmer et al., 1983) and changing and breaking cable systems (Stephens et al., 1982).

Behavioral Research

Throughout the decade, researchers have been trying to identify a key behavioral response by either the dolphins or the tuna that could be used to temporarily break the tuna-porpoise bond. Investigations, therefore, concentrated on mechanisms that could release dolphins from conventional purse seine nets (i.e., Phase-I work) and which might also serve as a basis for the development of alternate fishing systems not involving the capture of dolphin schools (Phase-II).

In their search to find ways to direct or elicit a predictable response (movement in a desired direction), researchers experimented with testing a wide range of acoustical signals on captured dolphins. Killer whale vocalizations to white noise and sounds of dolphins escaping were some of the signals tested. No underwater sound presented to captured dolphins has produced a response potentially useful in improving release efficiency. The first work was done in 1970 on the R/V *Miss Behavior* and the latest and most sophisticated work was done on the dedicated vessel,

Table 5.—Major malfunction categories showing frequency of occurrence, severity in terms of percent malfunction-related mortality, and average loss of time for each of the 4 years, 1977-80.

Malfunction	1977			1978			1979			1980		
	Sets f (%)	Kill %	Delay min.	Sets f (%)	Kill %	Delay min.	Sets f (%)	Kill %	Delay min.	Sets f (%)	Kill %	Delay min.
Speedboats	120 (15)	9.1	1.0	78 (21)	2.1	1.2	82 (30)	13.3	1.4	85 (32)	0	8.0
Roll-up	151 (18)	12.3	34.0	59 (15)	11.6	46.7	39 (14)	16.9	53.2	22 (8)	13	57.2
Net tangled in rings	129 (16)	12.8	16.1	42 (11)	28.7	19.3	31 (12)	4.6	15.2	29 (11)	34	26.5
Purse cable	94 (11)	12.5	17.9	27 (7)	15.3	11.9	22 (8)	23.7	16.3	12 (5)	7	22.4
Hydraulic problems	73 (9)	5.0	22.3	44 (12)	4.6	27.7	17 (6)	4.7	18.4	24 (9)	3	26.2
Bow bunches	41 (5)	5.1	5.8	37 (10)	2.0	15.9	22 (8)	5.6	14.9	14 (6)	1	7.7
Skiff	63 (8)	18.1	23.1	35 (9)	7.6	16.3	29 (11)	21.1	17.7	17 (6)	8	13.7
Winch and stripper				12 (3)	1.8	17.8	6 (2)	2.7	41.7	0 (0)	0	0
Other	144 (18)	22.5	20.3	44 (12)	26.1	11.9	23 (9)	7.4	15.8	60 (23)	34	21.3

M/V *Queen Mary* in 1978^{12, 13}.

Visual stimuli were also tested briefly on a cruise of the M/V *Margaret L.* (fall 1977) and on the dedicated vessel. A bubble screen, created by scattering chunks of dry ice across the backdown channel, was tested in several sets of the M/V *Margaret L.* The bubble screen did not produce a clear, consistent response by the dolphins. Underwater strobe lights and underwater magnesium flares were tested on the M/V *Queen Mary* cruises, both day and night, before and during backdown. These tests also showed that dolphins do not respond to these visual stimuli in any predictable way.

Under contract to NMFS, researchers at the University of Hawaii developed various concentrations of natural chemical extracts of prey species and organic debris to test the response of captured yellowfin tuna to olfactory stimuli¹⁴. The researchers were able to elicit strong feeding responses in laboratory tuna with these extracts. They hypothesized that

by presenting the extract that evoked the strongest response to tuna in the net they could be held stationary while the net was opened to release the dolphins. In field tests aboard the M/V *Queen Mary* in the summer of 1978, these olfactory lures did not produce a strong enough response by the tuna to warrant continuing the investigation. This contract research was ended in 1979.

Other Factors and Services Affecting Dolphin Mortality

Condition and Proper Use of Equipment

Much effort was expended on developing methods to alleviate many of the direct causes of mortality, but little had been done to address one of the more important indirect causes—malfunctions of machinery, gear, or procedures. These malfunctions were classified beginning in 1977 according to their relative contributions to dolphin mortality so that specific research areas could be identified (Table 5). Using these data, general recommendations for reducing rates and severity of some malfunctions have been prepared (Coe et al., In Press).

Operator Judgment

The captain's decisions are the most important factors influencing the outcome of tuna vessel operations. The level of experience and the amount of

information he possesses help him analyze circumstances and determine the best course of action. Any application of advanced technology or refinement in fishing procedures to reduce dolphin mortality will be decided by the vessel captain. The captain must either believe in the usefulness of changes or be required to incorporate them by law. The successful transfer of technology and information is a major key to the reduction of dolphin mortality.

Of the many methods that have been employed, the most effective one is a combination of the regulatory observer program and the enforcement regime. Prior to the existence of regulations governing gear and procedures (before 1976), skipper workshops were held and informal waterfront contacts were frequent while searching for volunteer vessels and captains to carry research observers. With the establishment of the mandatory observer program and vessel operator certification requirements, skipper training sessions (with mandatory attendance) were held. The regulated gear and procedures as well as the latest developments in mortality-reduction technology were presented at these sessions. "Marketing" methods for this information were not researched.

Extension Services

In 1977, NMFS established an extension service primarily to assist captains in the proper installation and

¹³Awbrey, F. T., T. Duffy, W. E. Evans, C. S. Johnson, W. Parks, and J. DeBeer. 1979. Summary of research results from the first leg of the third cruise of the dedicated vessel, June 22 to July 15, 1978. U.S. Dep. Commer., NOAA, NMFS, SWFC, Admin. Rep. LJ-79-11, La Jolla, Calif., 29 p.

¹⁴Ikehara, W. N., and J. E. Bardach. 1981. Chemosensory attracting and guiding of yellowfin tuna, *Thunnus albacares*. NOAA Contract 03-7-208-35268. U.S. Dep. Commer., NOAA, NMFS, SWFC Admin. Rep. LJ-81-07C, La Jolla, Calif., 42 p.

alignment of aprons, and also to disseminate information on other mortality-reduction techniques. The extension group monitored observer reports of incoming vessels for high kill rates and gear problems, and then met with the captains to discuss the problems on an informal basis. This work was coordinated with the NMFS Southwest Regional Office, the industry-sponsored Porpoise Rescue Foundation, and the Expert Skipper's Panel. The Expert Skipper's Panel, working directly with the extension group, has been very successful in the transfer of this information to the fleet by making captains aware of specific techniques and procedures for reducing dolphin mortality.

Discussion

The remarkable reduction of annual estimated dolphin mortality in the U.S. tuna fleet from 315,000 animals in 1970 to 16,900 animals in 1980 without any substantial changes in the basic fishing methods reflects two things. First, in 1970 there was tremendous potential for improvement in the standard tuna purse seine technology for release of dolphins without affecting fishing success. Second, the improvements were adopted by the fleet quite rapidly. The improvements, whether required by law or used voluntarily, appear to have had very little, if any, negative impact on fishing efficiency. Reductions in dolphin kill of this magnitude (from 70 animals per set in 1970 to about 3 per set in 1980) have shortened the average set duration. The improved methods and gear have been based on compatibility with existing purse seining technology, and as such have also been employed by many foreign tuna boats.

That more than a decade passed with the concentration in mortality-reduction research on the Phase-I objectives is not surprising when one considers the severity of the problem in the beginning and the fact that only one or two major field experiments aboard chartered vessels could be reasonably executed in any given

fishing year. Background information and experience had to be developed before experiments could be devised, and an incredibly broad range of ideas for solutions had to be evaluated. The diversity within the fleet coupled with limited research funds made designing experiments to meet stringent statistical requirements impossible. Even when economically and logistically acceptable gear and methods were devised, their introduction into practice was slow due to the traditional nature of the evolution of fishing systems and the difficulty in communicating with operators who were at sea 200-300 days a year.

The enactment of gear and procedural regulations by NMFS, coupled with the observer program, was instrumental in helping the fleet lower its kill rates in the shortest possible time. When carrying an observer aboard his vessel, a captain was under considerable pressure to use every technique at his disposal to minimize kill, since his performance was extrapolated to the entire fleet to monitor the kill quota (beginning in 1976). The frequency of observer trips (about 1 per year per vessel) and the resulting visibility of performance has served to create a competitive atmosphere among captains, raising their motivation and competence in dolphin release to very high levels.

As long as there is a management-oriented "porpoise observer program" and the annual kill quotas are reasonably close to levels attainable by the U.S. tuna fleet using present methods, there is every reason to expect kill rates to remain relatively unchanged. Kill rates may increase over time, however, if the extension services to the fleet are not continued on a high level. Kill rates cannot be expected to decrease significantly in the absence of technological improvements, since the fleet appears to have incorporated successfully nearly all mortality-reducing measures that are presently available. Mistakes are made, however, and accidents happen; occasional high-kill sets still occur. This is to be expected since the environment, dolphin behavior, and

equipment malfunctions are difficult for vessel captains to anticipate or control.

There is, however, the potential for developing fishing technology to further reduce the present dolphin kill rates. Investigations into the backdown operation had led to a basic understanding of the dynamics involved. Further investigations aimed at optimizing the configuration of the backdown channel and reducing the number and severity of canopies and premature net collapses hold a high degree of success. The idea of a dolphin-permeable backdown apex was never fully investigated and also deserves much more attention.

Information gathered on net designs from other purse seine fisheries where roll-ups do not occur would be useful in the elimination of that plaguing problem. The potential roll of model nets and computerized simulation models to investigate innovative net designs, alternative mesh configurations, and solutions to persistent mortality-related problems is great. These models also have the clear advantage of being less costly both in terms of time and money. Continued high-level support of the extension services to gather, analyze, and disseminate pertinent information on gear and machinery maintenance problems, dolphin rescue techniques, and operational procedures is very important. The timely transfer of their results and recommendations to the tuna purse seine fishery at large can be achieved through existing industry sponsored groups such as the Expert Skipper's Panel.

The results of implementing these ideas would bear directly on the kill rates of the present purse seine fleet. If reducing the total number of sets on dolphins can be considered as a partial solution to the problem, then a number of other research and development projects might be undertaken to increase the harvest efficiency for tunas not associated with dolphins.

Development of alternative fishing systems which do not entail the cap-

ture of dolphins when harvesting the associated yellowfin tuna, the full realization of the Phase-II goal, is a distant prospect. To begin addressing the idea will require a research program that is basic and broadly based, to fully delineate the nature of the tuna-dolphin bond, and to then develop a means to temporarily break or alter that bond. If these steps are satisfactorily completed, a modified fishing system to capture the tuna will then have to be devised. Such a system, of course, would have to be economically equal or superior to the present system and would have to be compatible with present-day vessel design, at least in the short run. Aside from the systematic rejection of a number of proposed solutions to this problem, very little progress has been made toward a realistic solution for the elimination of the incidental involvement of marine mammals in tuna purse seining.

Some very basic lessons have been learned in the course of this research. These lessons are generally applicable to most fishing technology problems. First, relative to industry relations:

1) In order to successfully research gear-technology problems in fisheries, the cooperation and confidence of the fishermen is essential.

2) Social systems and tradition are very important factors in the success or failure of technology transfer in fisheries.

3) Much of what fisheries technologists need to know to solve a problem is usually already known by someone in the fishery.

4) The fishing community will resist intervention regardless of how benign or progressive its intent.

Second, with regard to the conduct of applied research on fishing technology problems:

1) Enough vessel time is rarely available to adequately test and modify experimental gear and procedures.

2) In a fully operating commercial

fishery, organizing and fielding a well-designed experiment is extremely difficult because a large number of variables cannot be controlled.

3) Modification of the physical performance of fishing gear is often complicated by the lack of fixed points or fulcrums from which to exert desired forces.

4) With experimental vessel time at a premium, the probability of unfavorable experimental outcomes should be minimized through extensive shoreside investigations and preparations.

5) The amount of useful information which can be derived from observations and measurements taken only at the surface is limited. Remote sensing equipment and diving capabilities are essential for complete assessment of most fishing technology problems.

6) Fishing technology tailored to accommodate the natural behavior of the animals involved has a high probability of success.

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¹⁵The cruise reports in this bibliography are available through the Chief, Oceanic Fisheries Resources Division, Southwest Fisheries Center, P.O. Box 271, La Jolla, CA 92038. Contract reports, SWFC Administrative Reports, and NMFS Technical Memoranda are available through the Director of the Southwest Fisheries Center or directly from the individual authors. Articles published in independent journals are available from the authors.