SOUTHWEST FISHERIES SCIENCE CENTER

NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES SCIENCE CENTER P.O. BOX 271 LA JOLLA, CA 92038

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2ND DOLPHIN-SAFE RESEARCH PLANNING WORKSHOP: (MARCH 14-17, 1994) REPORT AND RECOMMENDATIONS

By

Elizabeth F. Edwards, Charles W. Oliver
and Joyce E. Sisson

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Report and Recommendations

Elizabeth F. Edwards

Charles W. Oliver

and

Joyce E. Sisson

Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038

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ABSTRACT

The 2nd Dolphin-Safe Research Planning Workshop was held at the Southwest Fisheries Science Center/NMFS, La Jolla, CA on March 14 - 17, 1994. The workshop focused on dolphin-safe methods of detecting and capturing large yellowfin tuna in the eastern tropical Pacific Ocean (ETP). Dolphin-safe methods are defined as those which do not involve intentional encirclement of dolphins. The workshop's primary objective was development of a research plan to guide activities within NMFS' Dolphin-Safe Research Program during the next 3-5 years, with emphasis on commercially promising detection methods. Workshop participants included technical experts familiar with various detection and capture methods, fishing experts familiar with the ETP tuna purse-seine fishery, and government agency scientists involved in the tuna-dolphin issue. Technical experts included representatives from military, academic, and commercial sectors. Fishery experts included representatives from the tuna fishing industries of the U.S. and Mexico, including fleet owners, fleet managers and vessel operators. Government agency scientists included representatives from the U.S. National Marine Fisheries Service, Mexico's Programa Nacional para el Aprovechamiento del Atun y Proteccion de los Delfines, and the InterAmerican Tropical Tuna Commission. Through the joint efforts of all participants, research priorities were identified as follows, in approximate order of importance;

- **preliminary modeling studies** of signal propagation and target signatures for acoustic, optic, and radar/SAR methods of detecting large yellowfin tuna in the ETP (FY95)
- **separation methods workshop** to evaluate potential for separating associated tunas and dolphins prior to capture (FY95)
- **validation experiments** in situ of promising detection methods (FY96)
- **acoustic survey** of abundance and distribution of large yellowfin tuna not associated with dolphins (if possible)(FY97)
- search for **correlations between environmental data and catch data** in existing data bases (FY97)
- **commercial system development** for detection technologies found to be promising in situ (FY98)

INTRODUCTION

In October 1991 (the beginning of fiscal year FY1992) the National Marine Fisheries Service (1992) initiated the Dolphin-Safe Research Program using newly appropriated funds from the U.S. Congress. The mandate for the Dolphin-Safe Program is development of new methods for locating and capturing large yellowfin tuna in the eastern tropical Pacific Ocean (ETP) without intentionally encircling dolphins. Dolphin-safe methods are required in this fishery for two reasons. First, the encirclement procedure has been responsible for much dolphin mortality and has led to current U.S. policy that dolphin mortality due to this fishing practice be reduced to zero. Second, bycatch problems associated with the other currently available fishing methods used to capture yellowfin tuna in the ETP have serious potential for damaging the commercial stock of yellowfin as well as other species (Edwards 1994[1], Hall[2])

A research planning workshop conducted in March of 1992 prioritized the suite of proposals for "dolphin-safe" research existing at that time. That prioritization directed funding of individual research projects in the Dolphin-Safe Research Program for fiscal years 1992 and 1993. With completion of the 4 top-ranked projects scheduled for late 1994, a second workshop was organized to determine research priorities for the future.

The second workshop was held March 14-17, 1994 at the Southwest Fisheries Science Center in La Jolla, CA. This report summarizes the workshop's objective, format, activities, and recommendations for future research.

METHODS

Objective

The workshop objective was identification, discussion, evaluation, and prioritization of proposed and promising research on alternative methods of detecting and capturing (without encirclement) the large (80-120 cm total length) yellowfin tuna that are currently caught in association with dolphins in the

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[1] Edwards, Elizabeth F. 1994. Bycatch of tuna from log, school and dolphin sets by the tuna purse-seine fleet in the eastern tropical Pacific Ocean, 1989-1992. Southwest Fisheries Science Center Administrative Report LJ-94-5.

[2] Hall, Martin. 1994. InterAmerican Topical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038. unpublished data.

ETP. Workshop participants were specifically instructed to limit discussions 1) to large yellowfin (excluding the smaller sizes vulnerable to other modes of fishing), 2) to the ETP (excluding other oceans with different oceanographic characteristics), 3) to detection methods other than dolphin cues, and 4) to capture methods that do not involve encirclement of dolphins.

This relatively narrow focus was chosen for two reasons. First, the large yellowfin tuna that associate with dolphins in the ETP are an abundant, valuable, and demonstrably sustainable resource that will be lost to commercial exploitation if dolphin fishing is eliminated and no alternative methods of detecting and capturing these fish are forthcoming. Second, a four-day workshop incorporating 3 disparate groups of players, each with their own expertise and interests, required a narrow focus in order to effectively accomplish our goal of a quantified research hierarchy by the close of the fourth day.

The specific topics chosen for discussion and evaluation at the workshop included acoustic, optic, and radar/SAR detection methods (the three most promising methods available currently or in the near term) and pair trawling (the most economically promising new capture method proposed to date).

Format

The workshop included four groups of participants, each group contributing a unique knowledge base and perspective to the workshop. The first group included technical experts familiar with the mechanics and physics of one or more of the three detection methods to be examined during the workshop. The second group included ETP purse-seine fishery experts with three different perspectives; 1) fleet owners(as overseers of fleet economics), 2) fleet managers (as experts in near-term fleet operations, and 3) vessel operators (as practicing experts in field operations of the fishery). The third group included government agency scientists familiar with the oceanography and ecology of the ETP ecosystem and with tuna-dolphin issues. The fourth group included an academic scientist and two New England Fishermen familiar with pair trawling for tuna in the Northwestern Atlantic.

Fishery experts included members from both the U.S. and Mexican fishing communities. Government agency scientists included representatives from the U.S. National Marine Fisheries Service (NMFS), Mexico's Programa Nacional para el Aprovechamiento del Atun y Proteccion de los Delfines (PNAAPD), and the InterAmerican Tropical Tuna Commission, an international agency concerned with conservation and management of yellowfin tuna stocks in the eastern tropical Pacific Ocean. Participation by fishery experts from Mexico was important because the Mexican fleet is by far the largest component of the current ETP tuna purse-seine fleet. Participation by government scientists from all three agencies was important because all three are actively involved in developing solutions to the tuna-dolphin problem.

Activities

The first three days of the workshop were devoted to discussions and evaluations of the detection and capture methods selected for review. The fourth day of the workshop was devoted to summarizing and synthesizing into a research plan the results from the discussions held during the previous three days.

On each of the discussion and evaluation days the workshop opened with a general description of the ETP tuna purse-seine fishery, including a summary of the physical environment, fishing practices, and tuna-dolphin ecology. This general description was followed by a brief review of research conducted to date, a video showing a typical purse-seine set, and a presentation of recent research results showing day-night differences in tuna and dolphin swim patterns in the ETP. This opening session was useful primarily to the technical experts who tended to be unfamiliar with the fishery prior to the workshop.

Following the opening session, Southwest Fisheries Science Center (SWFSC) scientists reviewed proposals that had been received by the Dolphin-Safe Research Program for research related to that day's detection or capture method, and asked that the technical experts introduce any newer or more effective methods that may have been missed. This proposal summary served to orient all workshop participants to the day's topic and to identify the types of projects or approaches to be discussed. Following the proposal summary, one or more of the technical experts presented an overview of the physics and current state of technology for the detection or capture method to be discussed that day. Acoustics were discussed on day 1, optics on day 2, with radar/SAR and pair trawling on day 3 (see agenda, Appendix I). This technical overview session was useful primarily to the scientists and fishermen who in general were unfamiliar with the technological details of the detection methods or their application in the ETP ocean environment.

An open discussion period followed these introductory sessions, during which workshop participants discussed the apparent potential of detection methods proposed to date and technical experts described briefly any additional promising approaches that had not yet been proposed.

When the open discussion reached a non-productive point (generally after all proposals had been discussed briefly and several *impromptu* conversations had arisen around the room) the session facilitator proceeded to assign each workshop participant to one of several small working groups. Each working group was assigned to develop answers for one or more of the questions or problems that had instigated the *impromptu* conversations. Each individual in each working group was assigned a role and groups were asked to reconvene after about an hour to discuss their progress and present their conclusions.

This strategy of following a general session involving all participants with a session of smaller working groups was primarily responsible for the efficient production of results during the workshop. Once all individuals had developed a common basis for discussion, it became necessary to adjourn to smaller groups in order to keep everyone focused on specific tasks.

By the end of each of the first three days, a general consensus was achieved regarding the important research projects(s) to be pursued for each detection or capture method and the priority for these projects. On the fourth day the results from the first three days were integrated into an overall research plan for the Dolphin-Safe Program, based on the intensive discussions held earlier. Participants in this integrative session included only a relatively small subset of the scientists and technical experts present during the previous three days because experience on earlier days demonstrated that a larger group would have been too unwieldy.

RESULTS

Acoustics

Technical background. In order to detect a target, acoustic detection systems must be able to discriminate between the signal associated with the target and all other acoustic energy (background sound) present in the medium, including reverberation associated with sonar equipment signals. Such systems can be categorized as active or passive, and as short-range or long-range. Active systems employ a sound source and depend on analysis of acoustic signals returned from a reflective target. Passive systems simply "listen" for acoustic signals generated by the environment (including, hopefully, the target). The target may generate determinable signals itself or may by its presence affect ambient signals in a recognizable way.

Short range detection usually involves analysis of higher frequency signals which allow one to achieve relatively greater target characterization. This method is especially useful for identification of target properties such as size, shape, and swimming characteristics of individuals. Long range methods depend on low frequency signals which propagate over long distances (e.g., miles) but provide less information.

Acoustic detection equipment can be deployed in a variety of ways, depending on the type of system employed. Possibilities include mounting on a ship's hull, towing by the ship, or deployment by helicopter either as dropped sonabouys or as dipping (continuously attached) sonar (although the latter is logistically complicated). Each type of deployment has advantages and disadvantages. The optimal system for any particular situation will depend on the acoustic characteristics of medium and target, both areas requiring preliminary study for applications in the ETP.

Regardless of the sensing device, acoustic signals can propagate over a number of paths from source to sensor (Figure 1). Common examples include direct path, surface duct, convergence zone, and bottom-bounce. In direct path propagation, sound proceeds directly from source to the target and returns by the same path. In surface duct propagation, sound is constrained to a narrow surface layer bounded below by the thermocline and may oscillate between the surface and the thermocline. In convergence zone propagation, sound paths are bent and focussed near the surface by variations in temperature with depth. In bottom bounce propagation, actively generated, long range acoustic signals are directed toward and "bounced" back from the bottom of the ocean. Targets are detected and located by "listening" for replicas of the transmitted sound (echoes).

The particular path actually realized in any situation is controlled by the characteristics of the transmission medium, the characteristics of transmission medium boundaries, the acoustic frequencies involved, and the equipment used. In the ocean, multipath propagation is the norm and complicates the design of sonar systems for detecting targets at longer ranges. Specific large-scale features that can affect sound propagation in the ocean, and therefore also the performance of sonar systems, include presence and frequency of large-scale inhomogeneities such as fronts, eddies, differing water masses and bottom topography. Specific small-scale features include thermal structure of the water column, density, salinity, currents, and proximity of surface, bottom, or other structures. In the ETP, the situation differs from most other oceans in that water temperatures in the upper mixed layer are warm and relatively invariant (27-30° C), water is fully saline (relatively little coastal influence throughout most of the area) and is generally clear (primary production is strongly nutrient limited). Currents (and thus density gradients) can be complex, but the biggest problem for currently available acoustic detection methods in the ETP is the relatively common presences of a negative gradient of temperature within the unusually shallow thermocline. Contrary to thermocline depths of 300-500 m in other oceans, the thermocline in the ETP is generally only 50-100 m deep. This is a serious problem for currently available commercial systems dependent upon high frequency, short wavelength signals because high frequency, short wave-length signals generated within the relatively shallow mixed layer near the surface are more likely to deflect downward and out of the layer than to travel laterally within it. This problem is the primary constraint upon the types of acoustic methods likely to work well in the ETP.

Fishermen's Interests. Fishing experts identified desirable characteristics for acoustic detection of large yellowfin tuna both for vessels with a helicopter and vessels without a helicopter. For vessels with a helicopter, fishermen were interested in a helicopter-mounted or deployed system that could detect fish within 5-20 miles, could identify fish schools containing at least 5-10 tons (preferably 2-3 times per day), and that could work at depths less than 300 feet. For all vessels (including those already equipped with a helicopter) fishermen were interested in a hull-mounted or possibly towed system that could identify fish depth and location relative to the vessel, estimate tonnage, identify species or at least the size of individuals, search at 10-15 knots, and include automatic target recognition and alert (to eliminate the need for constant human surveillance). ETP fishermen were especially interested in the potential for acoustic systems capable of long range detection (rather than short range biomass estimation) because fish schools are so scattered in this environment. ETP fishermen already have relatively effective short-range detection methods (e.g., bird radar to detect bird flocks), but lack methods to help them reduce the long distances they now search between schools.

Available Technology. Proposals received by the SWFSC for existing or developing acoustic detection systems include scanning, side-looking, and downward-looking active sonar, passive hydrophones, sonabouys, resonance techniques, sound generators, passive/active combinations, and low frequency detection/high frequency assessment combinations. The technical experts were familiar with these technologies and were especially interested in the potential for low frequency systems, subject to preliminary studies as discussed below.

Research Priorities. The technical experts recommended in this session a research direction that was reiterated subsequently for each of the other detection methods; preliminary mathematical modeling to assess the likelihood that a particular methodology would work in a commercial sense, given the constraints of searching for commercial quantities of large yellowfin tuna in the ETP environment. The technical experts unanimously recommended two preliminary modeling projects: 1) modelling of acoustic signal propagation within and below the shallow mixed layer of the ETP to provide preliminary estimates for design parameters (ranges, power, resolution, etc.), and 2) determination of acoustic target signatures of large yellowfin tuna to compare with design parameters. They were emphatic that these studies be completed prior to in situ testing or actual system development.

For estimating acoustic signal propagation, the technical experts recommended using existing mathematical models of sonar signal propagation, and incorporating into these models realistic ranges for estimated parameter values relating to the transmission medium (ETP sea water), the target (large yellowfin tuna or tuna schools), and the type of equipment being considered (e.g., passive vs. active, high vs. low frequency, etc.). Sophisticated microcomputer-based acoustic signal propagation models are widely available.

For estimating target strengths of large yellowfin tuna, participating biologists familiar with the logistic difficulties of experimenting directly with large pelagic tuna recommended a modeling approach. Direct measurements would require prohibitively expensive holding tanks or field enclosures, but computer models exist currently that could be adapted to provide reasonably accurate estimates given morphological measurements available from dead tuna[3].

The technical experts estimated that both the signal propagation and target signature studies could be accomplished 9-12 months for about $70,000 total cost. Further research into acoustic methods will depend upon the results achieved during these two fundamental projects. Exercising these models with various ranges of parameter values will provide a preliminary suite of estimates of efficacy for any given system, allowing apparently ineffectual systems to be eliminated from consideration and apparently effective systems to receive greater attention. For example, modeling can be used to examine the tradeoffs involved in developing a system to enhance response to the target signal while reducing response to background noise. Increasing the signal-to-noise ratio can increase the distance at which targets may be detected and reduce the number of false alarms, but cost will increase as well.

Two principal approaches exist for modeling acoustic signal propagation: ray tracing and mode theory. **Ray Tracing** assumes a horizontally stratified medium and is appropriate for predicting performance where sound wavelength is small in comparison with water depth and the desired range. Ray tracing predicts sound strength within the medium at all points between the source and receiver. Computer models exist which conveniently produce ray

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[3] The possibility of determining sound signatures for tuna from military records was discussed, but representatives from military establishments stated that the only biological sounds even roughly identified to date are from large whales. All others are simply considered "false targets".

diagrams. **Mode Theory** provides a solution to sonar equations through numerical calculation of signal intensity at specified depths and range as a function of time and frequency. Mode theory is considered complementary to ray tracing.

Because the location of the signal-source and receiver equipment is an integral part of any sonar design and performance, experts recommended that an analysis of various combinations of potential modes of sonar deployment for both the signal-source and receiver should be part of the preliminary modeling study. Potential modes recommended for consideration included hull-mounts, shallow towed arrays, deep towed arrays, floating arrays for use by individual vessels over a limited area, floating and submerged arrays anchored to the bottom for use by many vessels over a wider area, and for those vessels with helicopters, a dipping sonar package.

Results from both the signal propagation and target strength modeling projects will provide a basis for determining which acoustic detection methods have the greatest commercial potential for detecting large yellowfin tuna in the ETP environment. The modeling studies will be designed to provide predictions of performance (including minimum and maximum ranges, and associated resolutions) for various system designs and costs, using a range of parameters specific to the ETP tuna fishery.

The technical panel agreed that active systems would probably be more useful than passive systems for locating large yellowfin in the ETP, and recommended focusing on that approach. Passive systems are not likely to work at the ranges desired by the fishermen because tuna apparently produce only faint sounds, which would easily be lost between the fish and the fishermen. Active systems respond to self-generated, rather than target generated, signals and are much more likely to work effectively at distance from the vessel. The active direct-path systems available currently, which rely on high frequency signals, will probably not be useful in the ETP because these systems are appropriate mostly for short-range uses (1-2 miles). ETP tuna purse-seine fishermen are not particularly interested in this range; they are primarily interested in systems that can increase their detection probability at ranges of 5-10, or even 20 miles from their vessels.

Active systems that employ high frequency, indirect modes (e.g., surface channeling, convergence zone or bottom bounce methods) are more likely than direct path methods to provide practical solutions for the ETP tuna purse-seine fishery. Active systems that employ low frequencies are not likely to be practical because the high power requirements of such systems would require impractically large and unwieldy equipment.

Dipping and variable depth sonar methods have promise but will be relatively more expensive and complicated to operate than other methods because they involve separating the sound source from the vessel. Bottom bounce and convergence zone methods have promise but require higher power than the other methods, may be much more complicated to produce, detect, and analyze, and will yield only scattered coverage. However, these latter methods can be used to detect targets at extreme ranges (20-100 miles).

Passive systems are not promising because tuna do not make much noise, at least relative to other animals. Passive systems might be useful for close range identification but this capability would be unnecessary in the ETP because there are no other large, schooling, fast-swimming fish of similar size to the tuna that associate with dolphins. An alternative approach involving deployment of a widespread listening array was discussed but the problems of expense, ownership, vandalism, and upkeep were considered too great for such a system to be practical.

Optics

Technical Background. The physical constraints dictating propagation of light through water are absorption (primarily) and scattering (to a lesser degree). Dissolved and particulate substances (both inorganic and organic) influence water clarity by absorbing and scattering light; water itself also absorbs light. The depth to which light penetrates varies with wavelength, with shorter wavelengths absorbed at shallower depths. Thus, even distilled water appears blue (longer wavelength) at depth.

This concept can be expressed as the attenuation coefficient (k) in the simple equation for light intensity as function of distance from light source in water, $I_R = I_0e^{-kR}$, where R is range. k is larger in turbid water, smaller in clear water. In the offshore ETP, k is about 0.05 so that the corresponding attenuation length is about 20 meters. Because about two-thirds of available light is reduced with every attenuation length, approximately 96% of available light will have been lost at 60 meters and 99% at 80 meters depth. This does not imply that the human eye can distinguish objects at these depths, however. Although it is possible for the human eye to see a high reflectance object (e.g., a white Secchi disk or the silver flash or a tuna's side) at depths of 25-30 meters in clear water, tuna fishermen estimated they can only see (and follow) a school of dark-backed tuna (low reflectance) at depths to about 10 meters with unaided eye.

As with acoustics, two types of optical system are possible to extend these detection ranges; active systems and passive systems. Active systems direct a generated light source into the water and receive back reflected light from underwater objects.

These systems generally employ LIDAR (Light Detection and Ranging) technology, characterized by the use of a narrow band laser as the light source, and optimized filters and photodetectors designed to detect faint signal returns at specific wavelengths. Using narrow band lasers and filtered photodetectors, active systems should be able to detect objects at depths 3-6 times greater than the unaided human eye (e.g., 30-60 meters). Passive systems rely only on available visible light and generally use sophisticated signal processing techniques to enhance and/or detect contrasts invisible to the human eye. Even with the reduction of available light with depth, passive systems should be able to detect objects at depths 2-3 times greater than the human eye (e.g., 20-30 meters). Both systems survey an ocean area determined by system altitude above the ocean and detector field of view, with the latter constrained by the physical properties of light reflection and refraction.

There is little need to develop hull-mounted optical detection systems because existing acoustic systems provide better range and resolution for target detection. Ship-mounted optical systems are likely to be effective only at relatively limited depths with relatively narrow fields-of-view imposed by the proximity of the system to the ocean's surface. Airborne systems are preferable because higher altitudes provide a wider field of view and an aircraft's greater speed (50-100 knots versus 15 knots for tuna vessels) allows a much larger volume of water to be surveyed. For the ETP fishery, the most likely aerial platform would be the vessel's helicopter or perhaps a drone, flying a search pattern around and in front of the fishing vessel. Utilizing an optical system would enhance the standard visual search of surface conditions with a narrower swath, subsurface search to depths greater than visible to the human eye.

<u>Fishermen's Interests</u>. Fishermen described an ideal system as one capable of both detecting and identifying fish to any depth down to about 100 meters with a search swath width of about 1/2 mile by 1/2 mile, given a helicopter flying at the typical altitude of 1000-1500 feet. More realistically in terms of current or developing technology, fishermen said that they would be interested in any user friendly (not requiring a resident technician to operate) optic method that would improve their sighting efficiency over current visual, sonar, and radar methods. They would be willing to consider devices with a cost up to about $150,000 per unit. They would be willing to consider much more expensive technologies if the technology could replace the helicopter altogether, thereby eliminating the approximately $175,000 annual maintenance cost for helicopters owned by the fishermen, or the approximately $125,000 lease price per trip (with 2-4 trips per year common for most vessels).

Available Technology. Proposals received by the SWFSC Dolphin-Safe Program for active optical detection systems include several types of LIDAR systems (radiometric and imaging) and fluorescence imaging (wherein light is stimulated at one wavelength and emitted at other wavelengths). Proposals for passive detection systems include high-resolution video, high sensitivity video, infrared, dual channel imaging, multispectral imaging, and bioluminescence. The technical experts did not propose any new technologies, but were familiar with those proposed to date. As with acoustic methods, the technical experts were encouraging about only two of these approaches (LIDAR for active systems, enhanced video for passive systems), as discussed below.

Research Priorities. Regardless of the optical detection method selected, the technical experts recommended the same approach emphasized during the acoustics session, for the same reason. Before attempting to design an optical detection system, optical characteristics of both the ETP system and the desired target need to be defined. Based on these preliminary efforts, decisions can be made about the appropriate direction(s) for system development. Models for light propagation exist which are similar to those for propagation of sound. The optical properties of large yellowfin tuna, which need to be determined in order to design an optical system optimized for detection of these particular targets in the ETP, can be derived from specimens.

Once again, technical experts unanimously recommended preliminary modeling studies to predict performance of existing and proposed systems, and to provide estimates of range and cost for systems predicted to perform well in the ETP. As with acoustics, models exist for solving optical equations using known physical parameters (e.g., temperature, salinity, particulate content) and basic optical properties (refraction, reflection, diffraction). These parameters influence the optical propagation of light associated with the target, the transmission medium, and the equipment. The optical parameters required are few in number, and some are specific to the type of equipment used.

Of the proposals received by the Dolphin-Safe Program, technical experts selected for further discussion only LIDAR (for active methods) and high-sensitivity video (for passive methods) as practical optical systems for current or near future application in the ETP fishery. Other systems, while perhaps promising, were not considered to be as close to practical development and application.

LIDAR was the active optical system of choice because it can penetrate to great depths (30-60 meters in the clear waters of the ETP) and can be used during the day or night in all types of weather. LIDAR devices involve an unavoidable tradeoff between the area illuminated by the search beam and the depth to which it can penetrate and still detect return signals, although the volume of water surveyed can be increased by incorporating a scanning capability within whatever LIDAR beam and power specification is chosen. In the past, commercial fisheries use of LIDAR has been constrained by the costs associated with the exponential increase in power requirement for each additional attenuation length penetration (and linear increase for increases in area illumination). These increases lead to concomitant increases in size, weight and cost. However, technological progress in optical systems has been great during the last decade and smaller more powerful LIDARs are being developed. Military LIDAR developments in particular have been rapid and are becoming much more readily available to commercial and research projects.

High-sensitivity video was the passive optical system of choice because it appears to be readily attainable and relatively inexpensive. It would be effective primarily during daylight (bioluminescence at night might be an alterative imaging method) and even then only during periods of high solar elevation, but such a system could potentially increase imaging depth from about 10 meters with human eye and polarizing lens, to 10-20 meters with a video camera using a polarizing lens. With additional signal processing, a video system could probably detect images as deep as 30 meters and possibly as deep as 40 meters under ideal conditions. Such a system could potentially double or triple whatever volume of water is now observable with human eyes and reduce or eliminate many of the problems associated with the frailties of human vision (e.g., distractions, fatigue, glare, etc). A system could probably be built for $100,000 or less, particularly because software and hardware components are developing rapidly.

The technical experts agreed that studies were needed to define performance expectations and associated costs (e.g., area, depth, resolution, and money) specific to the needs of the ETP tuna fishermen and suggested that a variable scanning LIDAR may ultimately be the most useful system for this fishery. Variable scanning LIDAR can be adjusted to survey wider swaths (but with shallower penetration and relatively poorer resolution) or narrower swaths (but with deeper penetration and greater resolution).

Platforms for optical systems were discussed in terms of their relative usefulness to the ETP tuna fishery. Workshop participants agreed that the tuna vessel's helicopter or a drone would be the best platform for either a LIDAR or video system, primarily because the increased speed of the platform would provide a greater search area and provide the ability to rapidly assess potential fish sightings. Hull-mounted optical systems would not see far enough from the vessel underwater to be worth developing, particularly because sonar systems can do as well or better and perform under a wider range of conditions (e.g., turbid waters, night, overcast). Satellite images from the ETP are limited due both to lack of satellite coverage and frequent cloud cover. Land-based airplanes are impractical because much of the fishery operates far offshore in areas not within standard shipping lanes or airline routes.

RADAR/SAR

Technical Background. Radar is an active microwave system that emits electromagnetic radiation in the form of a radio frequency energy beam. Objects that interrupt this beam reflect part of the energy to a receiver, where the returning energy signal is analyzed to determine whether it corresponds to a desired target. The primary limitation in using radar for fish detection is that the signal does not penetrate or propagate through water to any appreciable extent. Aerial objects such as birds associated with feeding or near-surface tuna schools, or water surface disturbances created by near-surface tuna schools can be visualized with this method. A potential advantage to radar systems is their ability to work day or night, being unaffected by the presence of sunlight.

Three relevant scales exist for radar detection in the ETP, based on the platform carrying the radar. The tuna vessel itself is an appropriate platform for detection distances less than about 20 miles[4]. Radar-equipped aircraft would be appropriate for scales 20 - 100 miles, while satellites would be required for detection distances greater than about 100 miles. Because radar does not penetrate the water's surface to any appreciable degree, participants agreed that radar would not provide useful subsurface information at any range compared to existing detection methods.

Related technologies include thermal infrared systems, passive microwave systems, and Synthetic Aperture Radar (SAR). Thermal infrared systems passively receive shorter wavelength radiation (shorter than radar, although longer than visible). They record emittance from a very thin surface layer with little depth penetration. The potential for use at night to detect surface ripples (e.g., due to feeding schools of tuna) is a significant advantage of thermal infrared systems, but a

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[4] At the current time, s-band "bird radar" is often used successfully by tuna purse-seiners in the ETP to detect indirectly yellowfin tuna because seabird flocks are a common adjunct to feeding or near-surface tuna schools. The tuna vessels use s -band radar systems specifically adjusted for detection of small aerial objects within 10-12 miles of the vessel.

significant disadvantage is absorption (obscuring) of the signal by various atmospheric particles such as dust, water, and gases (O_2, O_3, CO_2). Passive microwave systems can operate day or night in almost all weather conditions and are less attenuated than infrared systems by clouds and fog. These systems operate in the same electromagnetic spectrum range as radar, but because they are passive do not generate any radiation.

SAR systems are active radar detection systems carried by aircraft and satellites. The system coherently processes signal returns over a period of time to produce an image of a surface similar to a photograph. In general, SAR is used to visualize large areas (several to several hundred square miles). A SAR system typically requires an aircraft flying for a long period of time over a wide swath of the surface being imaged. It has the potential to survey large areas (20-100 square miles) over periods of 5 minutes to an hour. Swath widths of 10-20 miles are common using either an aircraft or satellite, with potential for target resolution of 3 meters by 3 meters and "near"-real time processing of signal information. Imaged areas could extend from the tip of Baja California south to Guatemala and seaward several hundred miles. An example of current SAR imaging technology shows surface disturbances in the English Channel caused by bottom feature effects on overlying water currents. The resolution of this example is about 20 meters by 30 meters, but could be improved.

SAR systems would not visualize single birds but could probably identify disturbances caused by schooling fish, or oceanographic conditions favorable for fishing. SAR systems work equally well day or night, and also work well when clouds are present. A major disadvantage of SAR systems is that similar to a photograph, the image is produced from a relatively short time exposure (a few seconds to minutes) so that surface disturbances outside the imaging time will be missed.

<u>Fishermen's Interests</u>. Fishing experts were interested in three types of radar detection system; 1) a system that could increase the range and resolution of existing bird radar from about 10 to about 15 miles, 2) a system that would enable them to use their x-band RADAR to detect floating objects, and 3) a system that could replace the helicopter altogether. Because a replacement system would eliminate the cost of purchasing ($200,000-$300,000 used) and maintaining (approx. $175,000/yr) or leasing (approx. $125,000 per trip) a helicopter, fishing experts would be willing to consider relatively expensive radar systems.

<u>Available Technology</u>.
SAR: Most working SAR systems are currently owned and operated by various branches of the military. It is possible that these systems could be used on an occasional basis for fishery research, but under current configurations SAR systems are much

to expensive and large for use by individual tuna vessels. The only (remotely) practical use of existing systems might be cooperative use (and cost sharing) by the entire fleet or large fractions of it. At present, fixed-wing aircraft and/or satellites would be required to see surface effects of tuna schools such as breezers or feeding aggregations.

Existing systems are being used to study surface features in various ways, including for example 1) the effects of submerged features on surface patterns (e.g., the topography of the English Channel affecting properties of the water's surface across the Channel), 2) the potential for detecting surface effects at night using infrared, 3)doppler signatures of surface features (i.e., the velocity of surface features associated with ripples, wakes, upwellings). Great potential exists for improving existing systems, but it appears that SAR will not be a practical detection device for the ETP tuna fishery in the near future.

Research Priorities. Radar. As with optics and acoustics, it became obvious that signal propagation and target signatures need investigation prior to designing a radar system for ETP tuna purse-seiners. Radar target characteristics of surface disturbances caused by individual tuna and tuna schools, birds, and floating objects need to be identified so that required power, sensitivity, and associated design criteria (e.g., antenna size) can be estimated. A modeling exercise including simulated changes in system size, antenna height, and power could probably be accomplished for about $25,000 - $50,000.

A useful related study would investigate constraints associated with designing a helicopter-based radar (in particular, an improved s-band bird radar). For example, the 16 foot antennas used on tuna purse-seiners would obviously have to be modified. This modeling study could probably also be accomplished for about $10,000-$15,000. Existing helicopter-based radar could conceivably be rented on a short-term basis to investigate directly the target characteristics (e.g., doppler spectrum and time distributions) of visual cues such as breezers, floating objects, and so forth. These short term projects could probably be accomplished for about $50,000.

Indirect estimates of target signatures could perhaps be developed from existing data. A relatively low-cost alternative would be direct measurement of signatures generated by available fish schools, dolphins, floating objects, and seabirds within range of existing shore-based radar stations associated with military facilities (e.g., off Point Loma in San Diego, CA). Such a shore-based study might be accomplished for about $25,000, and would determine whether radar systems could improve the current ability of tuna fishermen to sight logs out to about 3 miles or greater, and breezers out to about 5 miles from the ship. However, the technical experts noted that a floating object with dimensions of 2 feet wide by 12 feet long with about 50% extending above the water (i.e., a "typical" log) would be considered a difficult radar target. Because fishermen indicated that they occasionally use their x-band radar to locate breezers, technical experts suggested conducting some local tests to determine the potential range and discrimination levels to detect surface schools using the x-band. Assuming promising shore-based results, subsequent tests could be made aboard ships at sea.

If results from these preliminary projects are promising, the possibility of night detection should be explored. In particular, radar experts suggested that a helicopter-mounted radar costing no more than about $45,000 after development, capable of detecting breezers and logs within about a 20-mile radius with a reasonably low false-alarm rate, was a realistic goal.

SAR. Development costs for a SAR system specifically for ETP purse-seiners would be prohibitive. Initial research costs alone would probably run into the millions of dollars, with eventual development of a satellite based system accessed by FAX from each vessel the most likely focus. SAR systems would not be appropriate for a single helicopter or for a single boat. Using such a system would require vessels working together and sharing the cost. A more practical approach, following characterization of target signatures, would be analysis of existing SAR images to determine whether any of the targets types have been recorded to date. Fishing experts indicated that they would be willing to travel 1000-1500 miles in response to images reliably indicating favorable conditions for fishing.

Pair Trawls

Technological Background. Pair trawling is a capture method that involves two vessels, each hauling one side of a very large but otherwise conventional mid-water trawl. The advantages to pair trawling are the large size of the net that can be accommodated and the relatively high towing speeds that can be attained. This potentially dolphin-safe technology is capture-based rather than detection-based, but is considered here for three reasons. First, pair trawling is the most economically promising non-purse-seine capture method proposed to date. The gear has good potential for high productivity, could probably be used day and night, and is relatively inexpensive to construct. Second, pair trawls have recently been successful in catching tuna in other oceans. Third, the method has promise as a relatively "low-bycatch" alternative to setting purse-seines around floating objects because theoretically the trawl could be deployed to catch only the organisms relatively deep in the water column, thus increasing the proportion of larger organisms in a given catch and reducing the catch of shallower (and generally smaller) individuals.

Pair trawling has promise for eliminating dolphin capture because dolphins swim quite close to the surface when swimming fast, as when chased by speed boats. By towing the trawl beneath the fast swimming dolphins and in the opposite direction, it is possible that some or all of the tuna swimming below could be captured in the net without simultaneously entrapping dolphins.

Although a promising dolphin-safe method, several potential problems and unanswered questions arose during workshop discussions of pair trawling. Many of the questions were related to behavior of tunas and dolphins in the presence of such gear. These questions can only be answered definitively by observing or tracking each species during passage of a trawl. A series of other questions also exists regarding the design and operation of such gear. As with most trawling operations, net design is a trade-off between size and towing speed. Mesh size in the fore-part of the net is also critical because drag and catching effectiveness must be considered. Large yellowfin tuna have never been caught in the ETP using large mesh trawls. There may be behavioral issues related to clarity or water temperature that render large mesh trawls ineffective.

Other unresolved questions involved engineering and operational procedures for pair trawling using purse-seiners. Adapting a seiner to pair trawling would require at least the efforts of a naval architect and a deck machinery engineer. Operational procedures associated with pair trawling require the coordination of two closely-matched towing vessels during maneuvers to pass tow cables from one vessel to another, and during trawling, plus acoustic-link trawl net monitoring equipment to monitor trawl depth and geometry. Trawling could not conducted with mismatched engines (i.e., between boats of very different sizes such as the seiner and the net boat). In addition, the configuration of tuna seiner engines, which are optimized for continuous high-speed cruising, may be incompatible with the slower velocities and heavier load capacities required by trawling. The seiner's propeller would also need to be changed from one optimized for steaming to one more suitable for towing, unless it has variable pitch.

The engineering of an effective pair trawl system for catching large yellowfin tuna in the ETP will not be a simple matter of transferring gear and methods from other fisheries, either. Thermocline depth, species behavior and swimming speed, vessel towing power and handling techniques will all influence system design.

Fishermen's Interests. The fishing experts were generally unenthusiastic about this method, primarily because they have a method that works (purse-seining) and they are loath to make expensive changes in gear and fishing procedure to fish a resource that has yet to be assessed. They were much more interested in methods to separate tunas and dolphins prior to capture while retaining their purse-seine gear. However, the fishing experts agreed that if the concept was demonstrated and shown to be economically viable, they would consider adopting the technology.

Available Technology. The pair trawl experts stated that pair trawls already exist and have been used successfully to capture tuna in other oceans. New ventures are also be starting; one of the meeting participants had recently purchased two trawlers with the intention of testing them for capturing tuna off the west coast of South America (Chile)[5]. There are net manufacturers in the U.S. experienced in design and manufacture of pair trawls. The capability exists, therefore, to design and build a pair trawl that might be suitable for use by two purse-seiners. Acoustic-link trawl net monitoring equipment that is probably suitable for ETP use is available commercially. The pair trawl experts also indicated that the techniques needed for locating schools of tuna would probably remain unchanged from present ETP techniques.

Research Priorities. Pair trawl experts recommended that a program of research be initiated aimed at evaluating the potential of pair trawling for large yellowfin tuna in the ETP, beginning with identification of differences and similarities between the ETP and other pelagic fisheries to determine if experimentation with existing pair trawlers might be productive. If so, then an initial experiment using these vessels might be feasible. If a pair-trawl experimental fishery showed potential, a subsequent effort would be needed to adapt two seiners to pair trawling. At present it is unclear whether these seiners would become combination vessels or whether their purse seining capabilities would be lost. These converted vessels would then be used to develop the most economical pair trawl methods for the ETP.

A more primary study not addressed by workshop participants but certainly necessary before the U.S> government commits significant effort in ETP pair trawl development, would be a thorough evaluation of the ecological and economic consequences of introducing this new type of gear to the already established purse-seine fishery in the ETP, including consideration of pair

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[5] Subsequent anecdotal reports indicate that gear has been very successful for hake and cod, although tuna have not been primary targets

trawling likely effect on the other fishing modes (school and log fishing) in addition to dolphin fishing. Past problems with fishery interactions and over-capitalization in other areas, and bycatch problems both in the ETP and elsewhere would need to be carefully addressed prior to U.S. government involvement in initiating a new fishery in the area.

Additional Topics

Survey. Another serious, fundamental problem hindering development of any detection or capture method was raised on the first day of the workshop. Specifically, very little is known about the distribution, abundance, and behavior of non-dolphin-associated large yellowfin tuna in the ETP. This is important because if there are not enough fish to support a fishery, then detection method development is largely irrelevant, at least for locating large yellowfin tuna not associated with dolphins in the ETP.

There is some evidence for the existence of non-associated large yellowfin but not enough to determine whether they represent a fishable resource. Large yellowfin are captured intermittently in both schoolfish and log sets[6], and fishermen report observing that newly released dolphin schools "pick up" tuna relatively quickly after release, and that large relatively isolated yellowfin can be seen from helicopters to coalesce under running dolphin herds during chase. In addition, longline catch records indicate that large and very large yellowfin can be found deeper in the water column, and recent tracking experiments have shown that dolphin-associated yellowfin can spend significant amounts of time unassociated with dolphins and at depths which preclude visual observation (Scott et al. 1994[7]).

Although these observations indicate that large yellowfin do exist unassociated with dolphins, it is unclear whether such fish exist and are vulnerable to capture in commercial quantities. Certainly with current fishing methods, effort required to capture large non-associated fish is considerably higher than that required to catch associated fish. Punsley and Fiedler

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[6] Punsley, R. and P. Fiedler 1994. Relationship between environmental factors and capture of large yellowfin tuna in the eastern tropical Pacific Ocean. MS in review. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038 (Punsely).

[7] Scott, Michael. 1994. InterAmerican Tropical Tuna Commission, c/o Scripps, Institute of Oceanography, La jolla, CA 92038. Unpublished results, 2nd Dolphin-Safe Research Cruise, Nov.-Dec. 1993.

(1994) found that search time, catch per set, catch rate and success rate were much lower for non-dolphin than for dolphin-associated fish.

Several fishing experts expressed doubt that economically useful quantities of non-associated large yellowfin exist in the ETP. Others expressed doubt that such fish could be captured, even if they did exist. The fishermen felt that trying to capture large yellowfin tuna without encircling dolphins would be fruitless because they believe that large non-associated yellowfin tuna in the ETP tend to be relatively scattered and relatively deep in the thermocline under most circumstances. Most fishing experts felt that large yellowfin only coalesce into schools in response to running herds of dolphins, which "draw up" the tuna from the depths during the chase. The fishing experts expressed doubt that a purse-seine could capture these larger fish without something to first collect and then to "hold" the fish together during a set.

Based on these discussions, workshop participants agreed unanimously on the need for a survey to determine locations, abundances, and spatial configurations of unassociated large yellowfin tuna in the ETP. Fishing experts emphasized the importance of determining whether non-associated large yellowfin occur as schools or only as scattered individuals because that will affect decisions about appropriate capture methods. Fishing experts were concerned in particular about the problem of "holding" non-associated schools long enough to capture them, should they exist.

Based on the discussions of various detection technologies, workshop participants agreed that acoustic methods offer the only practical possibility for conducting such a survey. This emphasizes the importance of the acoustic modeling projects to determine whether acoustic methods are feasible at all for the ETP. Analysis of existing long-line data for times and positions of large yellowfin capture might provide a rough picture of subsurface yellowfin distribution and abundance to aid in survey planning, but only a research survey can provide definitive answers upon which to evaluate the cost/benefit tradeoffs to developing potentially expensive new acoustic detection systems.

<u>Correlations</u>. Searching existing data sets for correlations between environmental parameters and catch data was another topic suggested repeatedly during the workshop. During the acoustics session, workshop participants suggested investigating existing environmental data bases in relation to catch data (log books) both as an aid to fishermen currently and to aid in designing an abundance and distribution survey. During the optics session, comparisons of satellite data and catch records were suggested. During the radar session, comparisons of existing SAR images and/or ordinary "real aperture" radar images (perhaps available

from military sources) with catch records were suggested. Accordingly, this topic appears in the research plan even though this sort of project was not originally included in the agenda for discussion.

Separation. A third topic unaddressed by the current workshop was also brought up repeatedly by interested fishing experts; the possibility of somehow separating the tunas and dolphins just prior to net set with purse-seines. Separation would retain the cue and aggregation features of dolphin-associated fish schools but avoid the problems with capture. This possibility has been suggested for many years but no obviously practical methods have yet been proposed for excluding dolphins from the purse-seine net prior to closure. The continued interest of fishing experts indicates that the subject warrants further evaluation, so plans are being developed to address the problem in a future workshop.

DISCUSSION

Possibilities

A relatively comprehensive picture of the possibilities for locating and capturing large yellowfin tuna in the ETP emerged from the extensive discussions during the first three days of the workshop (Figure 2). The basic uncertainties associated with developing an alternative to dolphin fishing, and the fundamental research questions that must be answered to address those uncertainties, became quite clear.

In general, success of any capture process will be affected by three or four distinct aspects of the process; distribution of the fish (horizontally and vertically), detection method, separation method (if necessary) and capture method.

Distribution is important because the most effective method(s) to detect, separate if necessary, and capture large yellowfin tuna in the ETP will depend upon whether the fish are scattered, schooled, or associated with either dolphins or floating objects, and whether the fish are near surface or at depth. If the fish are near surface and cause identifiable surface disturbances, SAR imaging may be appropriate. If the fish are near surface but not causing identifiable surface disturbances, optical detection (especially some form of LIDAR) is likely to be effective. If the fish are attracting birds, enhanced bird radar is likely to be useful. For fish within 5 meters of the surface, any of the optical or radar/SAR methods are likely to be as effective or possibly more effective than acoustical methods, which may have problems detecting near-surface fish due to acoustic interference associated with the air-water interface.

If fish are near-surface but too deep to produce a surface effect, SAR/radar will not be effective. Optical and acoustical methods will likely be most effective for these depths (5-50 meters).

If the fish are deeper than about 50-75 meters then optical detection methods are unlikely to be effective but acoustical methods still hold great promise. In fact, acoustical detection is the most promising method overall because acoustical detection range will far exceed optical detection range underwater under almost all circumstances (radar and SAR can only detect surface or airborne phenomena). The volume of water sampled by relatively long-range acoustical devices will be much greater than the volume accessible to optical search, therefore the probability of acoustical detection will be much higher. Optical systems will likely outperform acoustical systems only in short-range applications and only if water clarity is high. Under these conditions, a helicopter-mounted optical system may be able to search a larger area and greater volume than would be possible with a short-range acoustical system.

Fish distribution also affects the type of capture method most likely to be effective. For schooled or associated fish, either purse-seines or trawls will be effective. For scattered fish, trawls have promise but purse-seines would be ineffective. For dolphin-associated fish, separation prior to capture is necessary for the captured fish to be considered "dolphin safe". Two potential avenues exist for separation; mechanical and behavioral (subsuming here, avoidance or attraction behaviors related to chemistry). Pair trawling is a promising method of mechanical separation although ecological and economic consequences of introducing this gear need to be addressed prior to committing resources to its development. Other mechanical or behavioral methods have been proposed but preliminary tests, where they exist, have not been promising.

Recommendations

Based on this picture of the factors affecting dolphin-safe capture of large yellowfin tuna in the ETP, recommended research and research priorities emerged as discussed below.

Because large yellowfin tuna exist in the ETP in one of two states (either associated with dolphins or unassociated at least part of the time), there are two approaches that can be taken to locating and capturing these fish in a dolphin-safe manner.

For large yellowfin tuna <u>not associated</u> with dolphins in the ETP, capture depends first on detecting the fish in the absence of their dolphin cue. The approach required here can be summarized as three successive questions; 1) can we find the fish, 2) are there commercial quantities of fish, and 3) can we develop a commercial system to find them (Figure 3)? Acoustical, optical, and radar/SAR detection methods all offer promise, but before these methods can be tested to detect the fish, the efficacy of each detection method has to be evaluated for the ETP environment and for the desired target (large yellowfin tuna). Technical experts unanimously recommended the same two **preliminary modeling studies** for all three detection methods; 1) mathematical modeling of signal propagation in the ETP environment, and 2) determination of target signature(s) either by direct measurement or modeling. Promising results from the preliminary modeling phase should be followed by **validation experiments** in the ETP environment.

Whether capture is worth pursuing once the fish are detected then depends upon whether there are commercially exploitable numbers of them. Provided the acoustical models are promising, acoustical modeling and validation studies should be followed immediately by planning and deployment of an **acoustic survey** to determine distribution and abundance of large non-associated yellowfin tuna in order to assess whether fishable quantities exist in the ETP. Such a survey will have to be acoustics-based as only acoustics will be appropriate for a wide-area, subsurface survey. If results from both the validation experiments and the acoustical survey are promising, then resources should begin to flow into **system development** for a commercially available acoustic detection system at a reasonably accessible price (Figure 4).

If acoustical models or results from the acoustical survey are unpromising, then the arduous and often unrewarding task of examining large, unwieldy, and disparate data sets for **correlations between environment and catch data** (as a proxy for fish distribution and abundance) becomes more important.

For large yellowfin tuna that <u>are</u> <u>associated</u> with dolphins in the ETP, detection is not a problem (although enhancements are always desirable) but the capture process is. The (conceptually) simplest approach to capturing dolphin-safe dolphin-associated large yellowfin tuna in the ETP would be to use some capture method that separated the two groups just prior to capture by purse-seine. In this case, the obviously effective current procedures of sighting, evaluating by helicopter, chasing with speedboats, and capturing with purse-seines could continue. Unfortunately, no separation method proposed to date appears to offer much practical hope. Regardless, the concept of separation prior to capture has been suggested repeatedly by fishing experts and therefore deserves closer examination. Thus, workshop participants recommended organizing a **separation methods workshop** similar to the current detection and capture methods workshop, with the objective of identifying and evaluating the potential of various proposed separation techniques.

A second (conceptually) simple approach to capturing dolphin-safe fish is use of alternative gear that mechanically separates the groups, e.g., pair trawling. Although a promising capture method, pair trawl research is not included in the research plan at this point because the majority of workshop participants felt that more progress could be made toward achieving Dolphin-Safe fishing goals by allocating the limited funding currently available to the preliminary modeling studies and to further examination of the possibility of separating tunas and dolphins prior to capture by purse-seine. Gear and methods development research, such as that envisioned for pair trawling, is expensive and is currently beyond the budget limitations of the Dolphin-Safe Program. In addition, prior to initiating such research, it will be necessary first to examine carefully the potential ecological and economic consequences of introducing this new gear to the established purse-seine fishery in the ETP, including the issues of potential fishery interactions, overcapitalization, and bycatch. If progress in detection technologies are unpromising, in particular the results of acoustical surveys to assess the potential for a non-dolphin-associated fishery for large yellowfin tuna in the ETP, then introducing alternative gear will receive increasing interest. However, the possibility of solving the existing problem, using new detection technologies but existing gear, remains the most efficient and least intrusive of current possibilities.

ACKNOWLEDGEMENTS

This workshop could not have been completed without the cooperation and good will evidenced by the various organizations and individuals who were willing to donate their time and expertise to furthering our search for dolphin-safe fishing methods in the ETP. We thank the USAID for facilitating the travel of our non-U.S. participants. We thank Wes Armstrong of the Dolphin-Safe Research Program for his ability to be all things to all people, as was needed. We thank the technical experts for their reviews of their respective sections of the report. Any remaining errors are due solely to the authors.

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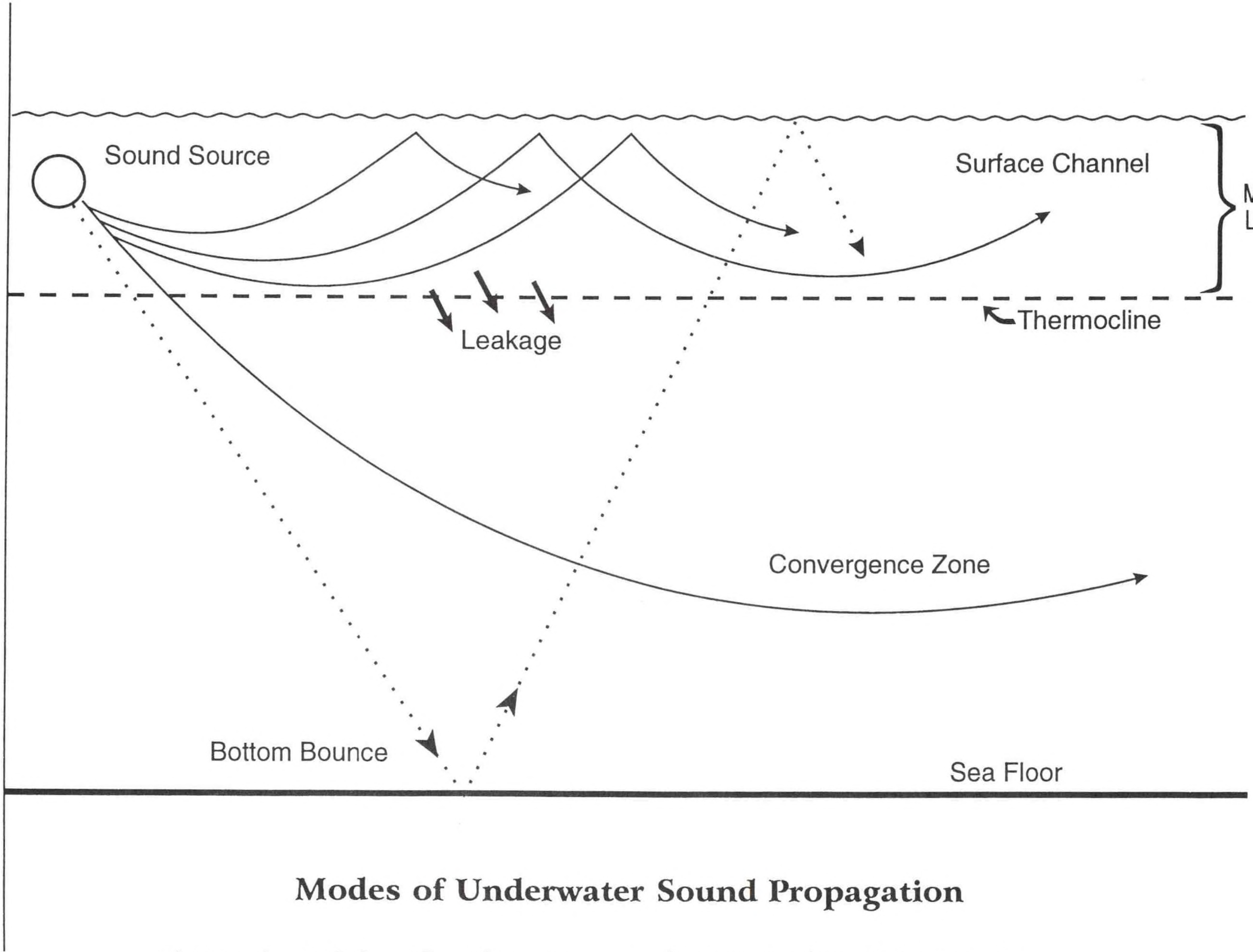


Modes of Underwater Sound Propagation

Figure 1. Models of underwater sound propagation (adapted from Thomas and Evans 1982)

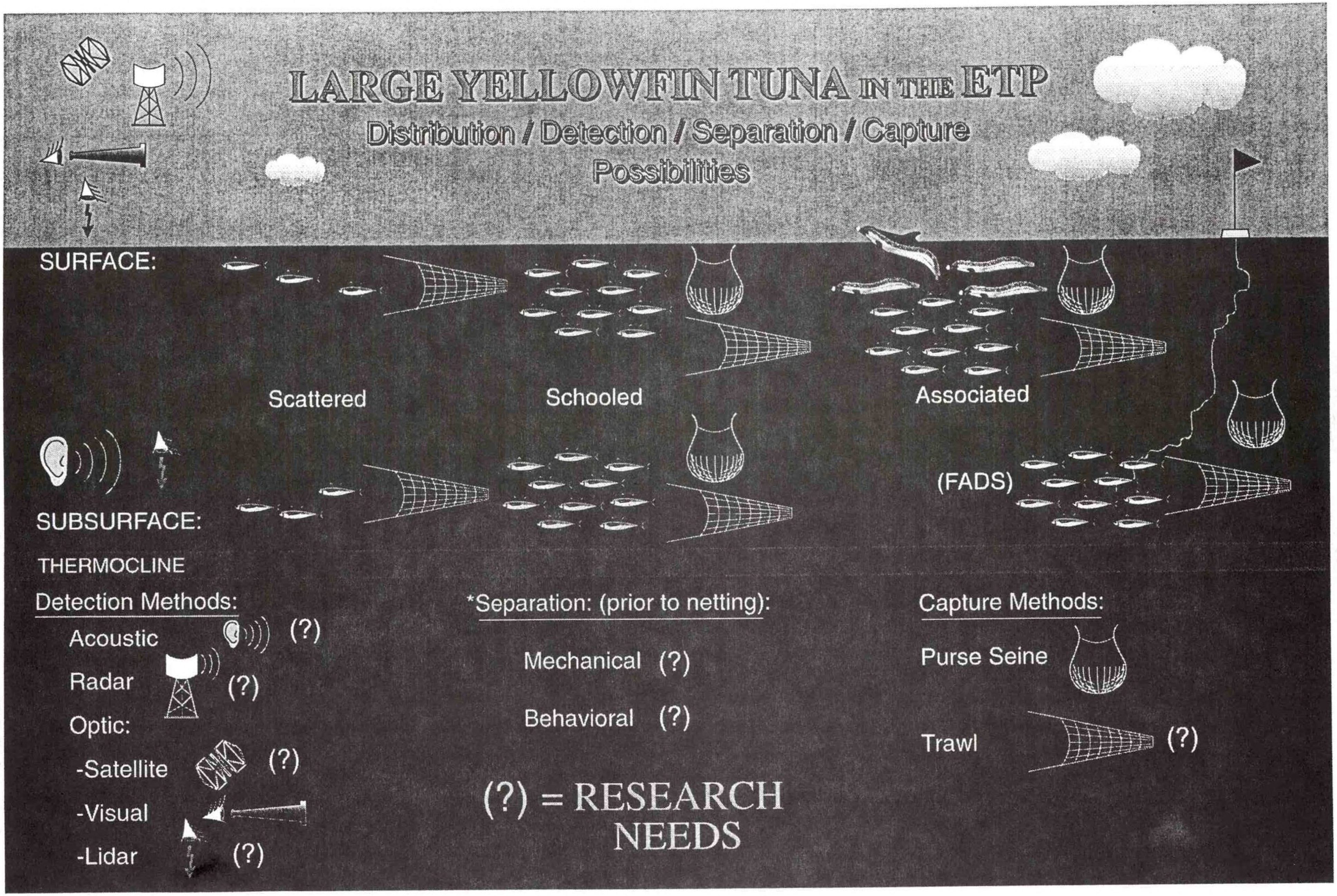
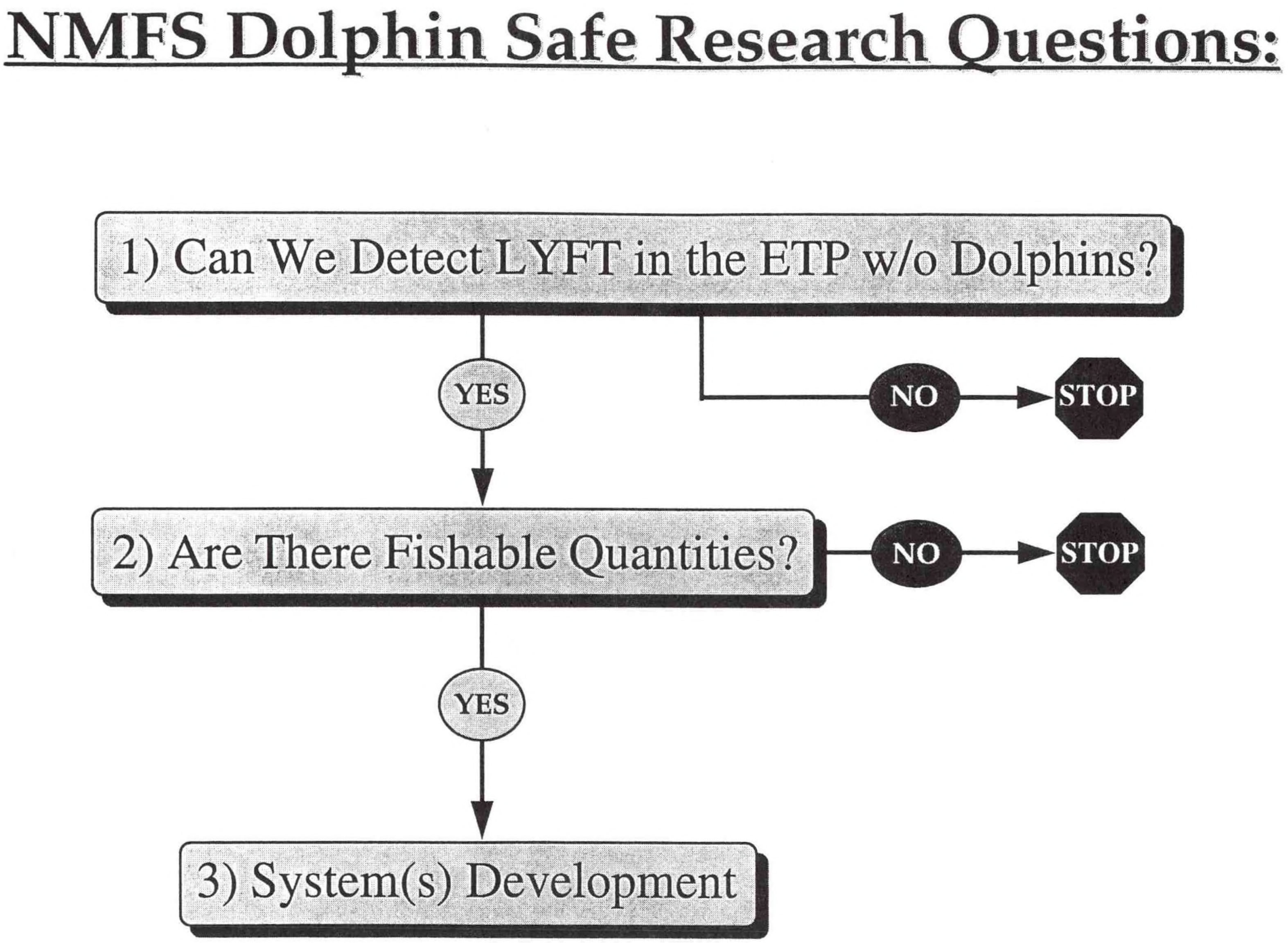


Figure 2. Possibilities for locating and capturing large yellowfin tuna in the eastern tropical Pacific Ocean.



NMFS Dolphin Safe Research Questions:

Figure 3. Research sequence for yellowfin tuna not associated with dolphins.

Dolphin-Safe Workshop Recommendations

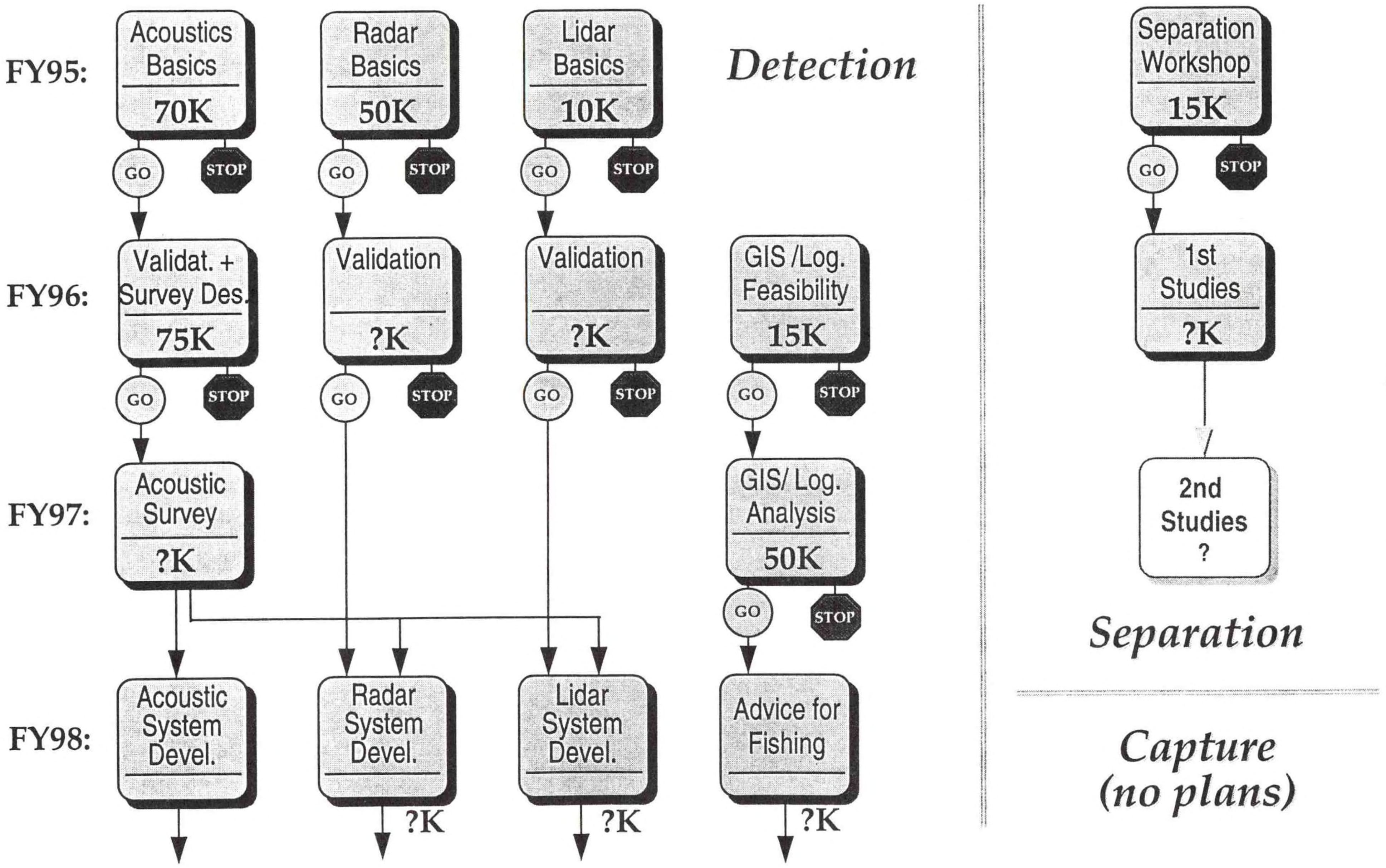


Figure 4. Temporal priorities and estimated costs of recommended dolphin-safe research projects.

Appendix 1. Meeting Agenda

Dolphin-Safe Research Planning Workshop
March 14 - 17, 1994
Southwest Fisheries Science Center
La Jolla, CA

Agenda

Monday, 14 March: ACOUSTIC detection methods

8:30 AM - 9:00 AM:
Introduction (workshop objectives, background material)
9:00 AM - 12:00 PM:
technology descriptions and discussions
12:00 - 1:00 lunch
1:00 PM - 5:00 PM:
determine required experiments, costs
7:00 PM - ... :
continued discussions if necessary

Tuesday, 15 March: OPTIC detection methods

8:30 AM - 9:00 AM:
Introduction (workshop objectives, background material)
9:00 AM - 12:00 PM:
technology descriptions and discussions
12:00 - 1:00 lunch
1:00 PM - 5:00 PM:
determine required experiments, costs
7:00 PM - ... :
continued discussions if necessary

Dolphin-Safe Workshop Agenda, cont'd.

Wednesday, 16 March: I) RADAR/SAR detection methods
II) pair trawling capture methods

8:30 AM - 9:00 AM:
Introduction (workshop objectives, background material)
9:00 AM - 12:00 PM:
Radar descriptions and discussions;
12:00 - 1:00 lunch
1:00 PM - 2:00 PM:
determine required RADAR experiments, costs
2:00-5:00 PM:
pair trawl description, discussion, experiments, costs

Schedule, Thursday:

9:00 AM - 3:00 PM: discussions and computer games
(integration of experiments proposed Mon-Wed,
development of research hierarchy)

3:00 PM - 5:00 PM: summary and development of consensus

Participants

ALL 4 DAYS:

Facilitators:

- Dr. Tony Starfield
- Dr. Katherine Ralls

Oceanographer

- Dr. Paul Fiedler

Agency scientists:

- Dr. Elizabeth Edwards (NMFS)
- Mr. Chuck Oliver (NMFS)
- Dr. Michael Scott and/or Mr. Dave Bratten (IATTC)
- Dr. Guillermo Compean (PNAAPD)

Fishery Representatives:

- Mr. Cary Gann
- Ms. Teresa Platt
- Mr. Ignacio Gavaldon (15 March only)
- Mr. Jose Carranza
- Mr. Ernesto Escobar
- U.S. fleet skipper(s)
- Mexican fleet skipper(s)

Rapporteur:

- Ms. Joyce Sisson (NMFS)

SPECIALISTS ATTENDING 1-DAY SESSIONS:

Monday, 14 March: Acoustics:

- Dr. Jules Jaffe
- Dr. D. V. Holliday
- Dr. Marc Montroll

Tuesday, 15 March: Optics

- Dr. Jules Jaffe
- Dr. Mike Lovern
- Dr. Jim Stachnik

Wednesday, 16 March: RADAR/SAR, Pair Trawling

Dr. Bob Dinger	(RADAR)
Dr. Byron Summers	(RADAR)
Dr. Charles Weller	(RADAR)
Dr. Cliff Goudey	(pair trawls)
Ms. Teresa Platt	(pair-trawls)
Mr. John Riemer	(pair-trawls)

Appendix 2. Participant List, 2nd Dolphin-Safe Research Planning Workshop

Mr. David Bratten
InterAmerican Tropical Tuna Commission
c/o Scripps Institute of Oceanography
La Jolla, Ca 92038
619-546-7043
619-546- 7133 (FAX)
fishery specialist

Mr. Randy Caniglia
3577 Syracruse Avenue
San Diego, CA 92122
619-453-7358
Tuna vessel Captain (AZTECA, Mexico)

Mr. Jose E. Carranza
PESCA AZTECA
Ave. Pto. Manzanillo
y Puerto Varacruz s/n
Parque Industrial Alfredo V. Bonfil
Mazatlan, Sinaloa, Mexico
011-52-69-825210
011-52-69-822103
011-52-69-851895 (FAX)
011-52-69-821844 (FAX #2)
President, Pesca Azteca

Mr. Ralph Carvalho
942 Rosecrans Blvd.
San Diego, CA 92106
619-223-8962
Tuna vessel Captain (US)

Mr. Greg Chase
3714 Rosecraft Lane
San Diego, CA 92106
619-223-4143
Tuna vessel Captain (US)

Participant List, Dolphin-Safe Workshop, cont'd.

Dr. Guillermo Compean
Director, Programa Nacional para el
Aprovechamiento de Atun y Proteccion
de los Delfines
Secretaria de Pesca
Avenida Espinoza N° 843, (CICESE)
Colonia Obrera
Ensenada B.C.
Mexico
011-52-667-72438
011-52-667-72437 (FAX)
fishery specialist

Mr. Larry Da Rosa
S&A Management
P.O. Box 28253
Escondido, CA 92128
619-223-6147
Tuna vessel owner/Captain (US)

Dr. Bob Dinger
Naval Command Control & Ocean Surveillance Center
RDT&E Division, NRAD
Code 755
San Diego, CA 92152
619-553-2500
619-553-1130 FAX
radar

Dr. Elizabeth Edwards
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
619-546-7099
619-546-7003 (FAX)
Fishery specialist

Participant List, Dolphin-Safe Workshop, cont'd.

Mr. Ernesto Escobar
PESCA AZTECA
Ave. Pto. Manzanillo
y Puerto Varacruz s/n
Parque Industrial Alfredo V. Bonfil
Mazatlan, Sinaloa, Mexico
011-52-69-825210
011-52-69-822103
011-52-69-851895 (FAX)
011-52-69-821844 (FAX #2)
operations manager

Mr. Frank Fera
P.O. Box 658
Spring Valley, CA 92077
619-670-7744
Tuna vessel Captain (AZTECA, Mexico)

Dr. Paul Fiedler
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
619-546-7016
619-546-7003 (FAX)
ETP oceanography

Mr. John Freitas
3616 Garrison St.
San Diego, CA 92106
619-222-5054
Tuna vessel owner/Captain (US)

Mr. Cary Gann
Caribbean Marine Service
P.O. Box 5035
Rancho Santa Fe, CA 92067
619-759-1210
619-759-1299 (FAX)
fleet manager

Participant List, Dolphin-Safe Workshop, cont'd.

Mr. Ignacio Gavaldon
GRUPO NAIR S.A. de C.V.
Calle Warta y Ave. Miramar
Locales 3 y 4
Ensenada B.C. , Mexico
011-52-617-83003 (FAX)
fleet manager

Dr. Cliff Goudey
Massachusetts Institute of Technology
Bldg. E-38-372
292 Main Street
Cambridge, MA 02139
617-253-7079
617-253-5730 (FAX)
pair trawl design

Dr. D. V. Holliday
Director of Research, AARD
TRACOR Applied Sciences, Inc.
9150 Chesapeake Drive
San Diego, CA 92123
619-268-9777
619-268-9777 (FAX)
acoustics

Dr. Jules Jaffe (SIO)
Assistant Research Oceanographer
Marine Physical Laboratory (0205)
Scripps Institute of Oceanography
La Jolla, CA 92083
619-534-6101
619-534-7641 (FAX)
jjaffe@ucsd
acoustics, optics

Participant List, Dolphin-Safe Workshop, cont'd.

Dr. Mike Lovern
Naval Command Control and Ocean Surveillance Center
NCCOSC RDTE DIV Code 843
53490 Dow St., Rm 110D
San Diego, CA 92152-5732
619-553-3724
619-553-6449 (FAX)
Lovern@NOSC.MIL
asst: Bob Gisner (marine mammologist) 553-5592/5593
optics

Mr. Harold Medina
3128 Via Caliente del Sol
Jamul, CA 91935
619-669-1063
Tuna vessel owner/Captain (US)

Dr. Marc Montroll
Naval Surface Warfare Center
Carderock Division Code 74
Bethesda, MD 20084-5000
301-227-1555
acoustics

Mr. Charles Oliver
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA 92038
619-546-7172
619-546-7003 (FAX)
fishery specialist

Ms. Teresa Platt
826 Orange Ave.
No. 504
Coronado, Ca 92118
619-575-4664
619-575-5578 (FAX)
tuna industry representative

Participant List, Dolphin-Safe Workshop, cont'd.

Mr. Patricio Quintanilla
PESCADOS de COLIMA S.A. de C.V.
Calle Central Oriente # 5
Parque Industrial Fondeport
Manzanillo, Colima, Mexico
011-52-333-24540
011-52-333-24127 (FAX)
fleet manager

Dr. Katherine Ralls
2775 Miderer Road
Paso Robles, CA 93446
805-237-0795
facilitator

Mr. John Riemer
31 Lewiston Ave.
West Kingston, RI 02892
401-364-0018
401-364-1072
pair trawl fisherman

Dr. Michael Scott
InterAmerican Tropical Tuna Commission
c/o Scripps Institute of Oceanography
La Jolla, Ca 92038
619-546-7043
619-546- 7133 (FAX)
fishery specialist

Ms. Joyce Sisson
Southwest Fisheries Science Center
P.O. Box 271, La Jolla, CA 92038
619-56-7064
619-546-7003 (FAX)
rappateur

Participant List, Dolphin-Safe Workshop, cont'd.

Dr. William J. Stachnik
Office of Naval Research
Applied Research and Technology Directorate
Surveillance and Communications Division
Ocean Optics
495 Summer Street
Boston MA 02210
617-451-3176 3/2/94
617-728-3256 FAX
3/3-3/4/94 DC 706-696-5722 or 5723
optics

Dr. Tony Starfield
Dept. Ecology and Behavioral Biology
109 Zoology Building
318 Church Street S.E.
Minneapolis, MN 55455
612-625-4466
facilitator

Dr. Byron Summers
Naval Command Control & Ocean Surveillance Center
RDT&E Division, NRAD
Code 7501
San Diego, CA 92152
619-553-2451
619-553-1130 FAX
radar

Mr. Phil Virissimo
3601 Voltaire St.
San Diego, CA 92106
619-222-3194
Tuna vessel Captain (US)

Dr. Charles Weller
Naval Surface Warfare Center
Carderock Division Code 1402
Bethesda, MD 20084-5000
301-227-1274
radar