Northeast Fisheries Science Center Reference Document 93-08

Workshop on Tagging and Tracking Technology

Report of a scientific workshop held February 11-13, 1992, Airlie House, Warrenton, Virginia

NOAA/ National Marine Fisheries Service
Northeast Fisheries Science Center
Conservation and Utilization Division
Marine Mammal Investigation
Woods Hole, MA 02543-1097

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Prepared by
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EXECUTIVE SUMMARY

The difficulties associated with collecting reliable information on marine mammals — their movements, habitat use, activity patterns, ecology, and behavioral and physiological responses to environmental and anthropogenic activities — can be significant and often overwhelming. The nature of the environment that these animals inhabit, which includes distant, open oceans and ice-covered areas, often precludes or limits the use of conventional research platforms. In those instances where ships and aircraft are available, the accompanying costs, logistics demands, and safety constraints can be prohibitive. This has limited present knowledge primarily to coastal regions.

There is reason to expect that the situation may change. Satellite-based telemetry appears to be the most promising approach for following marine mammals throughout their entire ranges to gain a more accurate understanding of both the animals and the environments critical to their survival.

Advances in electronic and computer technology have been phenomenal during the past few years, and continued improvement is anticipated. This dynamic situation has greatly affected radio, sonic, and satellite-linked tagging technology that is being applied to the study of marine mammals, as well as terrestrial and avian species. It is important that funding agencies, engineering and consulting firms, and researchers remain current with the field to better understand and manage marine mammals.

A Workshop on Tagging and Tracking Technology was held from February 11-13, 1992, at the Airlie House in Warrenton, Virginia. Its purpose was to review past approaches, describe the state-of-the-art technology presently being applied to marine mammal research, and identify areas where further research and development efforts may be needed. The meeting was jointly sponsored by the Office of Naval Research, the Minerals Management Service, the National Marine Fisheries Service, and the Marine Mammal Commission. Participants included researchers from the United States, Great Britain, Canada, Norway, and Japan with direct experience in tagging and tracking marine, terrestrial, and avian species. Representatives of engineering and consulting firms involved in developing radio tags, along with representatives of the sponsoring agencies, the U.S. Navy, the U.S. Fish and Wildlife Service, and the British Sea Mammal Research Unit also participated in the workshop.

The objectives of the workshop were to: (1) describe user interests, needs, and requirements; (2) determine the state-of-the-art of instrumentation and sensors, attachment techniques, and data acquisition and analysis; (3) identify the problems and deficiencies in existing technology that must be overcome to effectively meet users interests and requirements; and (4) to identify what needs to be done to overcome the problems and provide estimates of the time and cost needed to accomplish identified needs.

These objectives were addressed first through a general review of past and current tags and methods being applied in marine mammal research. Participants then split into three working groups to address particular aspects of the issue. The three working groups focused on: (1) tag delivery, attachment and release systems; (2) instrumentation; and (3) data transmission and analysis. The following recommendations resulted from the working group discussions.

SUMMARY OF WORKING GROUP RECOMMENDATIONS

NEEDED RESEARCH AND DEVELOPMENT

1. Systematic research on the basic behavioral and physiological effects of attaching instruments to captive and wild cetaceans should be funded and facilitated by a consortium of government agencies. This study is needed because future research could be regulated on the basis of potential harm that might result from use of such tagging methods.
2. A research program is needed to address attachment methods, the hydrodynamic drag and energetic costs of various package shapes and sizes, materials for both the internal (implanted) and external components of tagging systems, tissue and animal responses to various attachment techniques, and longevity of these same techniques. In a first phase of this program, captive animals housed in natural sea water, such as at the Naval Ocean Systems Center, should be used. A second phase should use animals in resident populations (both small and large cetaceans) to test attachment longevity. Concerned government agencies should cooperate to main-

tain a long-term testing program and database.

3. Research should be conducted into the question of which is preferable: attachments into muscle or into blubber.
4. Devices should be developed for remotely releasing and retrieving externally mounted instruments.
5. A basic tag should be developed that is essentially a data logger. The device should be modular in design yet flexibly configured. It should provide location, dive, and temperature data, with a peripheral device that provides high accuracy location data.
6. The basic tag should offer menu choices. When microprocessors capable of addressing 640 K become sufficiently small, the advanced tag should use programming in a higher-level language (*i.e.*, C++) to allow greater researcher flexibility and, when low earth-orbiting (LEO) satellites are available, to allow reprogramming of units already deployed.
7. An advanced tag should be developed that elaborates on the information obtained by the basic tag, using specialized sensors that focus on special aspects of diving such as foraging and/or measurement of physiological variables.
8. Researchers should work with Service Argos to develop ways to describe the distribution and causes of errors associated with each location type. Filtering algorithms should be developed that will aid in the interpretation of location fixes (especially class 0 locations) with variable and/or unknown confidence limits.
9. The Instrumentation Working Group's ranked preference for needed biological sensors is (in order): orientation, heart rate, velocity, feeding, acoustic, respiration, and conductivity; each is associated with varying developmental times.
10. Radio frequency transmission capabilities should be developed for handling digital data at rates of tens of kilobytes per second for near-term use and at rates of hundreds of kilobytes per second for longer term needs. Associated data processing techniques need to be developed to send data to the radio frequency transmitter in an order of priority that maximizes data return during any one transmitter exposure.
11. The most promising future swim velocity meters will use acoustic transducers at each end of the package to compare forward and backward doppler shifts. The long-term goal is to measure animal velocity with reference to unmoving water a few tens of centimeters from the animal's surface.
12. A feasibility study should be undertaken on using changing water pressure as a source of electrical power. The study should consider how much pressure differential develops during individual dives and how to convert and store this as electrical energy.
13. Calibration data should be recorded along with data stream for future conversions into real values in the absence of having access to the original calibration curves.
14. Further investigation is needed on the use of fiber optic cable for short-term, very high data transfer rates.
15. Discussions should take place with global positioning system (GPS) designers to determine whether it is feasible to develop a location device that meets the space and power requirements of most marine mammal researchers.

RECOMMENDED ATTACHMENT PROCEDURES

1. The smallest possible instruments, bearing the name and address of the owner, should be deployed with any attachment method.
2. Suction cup attachments are recommended for short-term deployments (1 to 4 days) on smooth-skinned cetaceans and should have built-in release devices. It is recognized that the cups may migrate and pressure necrosis may occur on the skin of some species.
3. For instrument attachment on large cetaceans that cannot be captured, subdermal attachments should be delivered by shotgun or crossbow. This procedure requires extensive training and experience to ensure accurate placement. Crossbows have a greater margin of safety due to the lower velocities.
4. Mounts that include bolting through some dorsal structure, such as a fin or ridge, should be used for deployments intended to last more than one month. This appears to be the best method of attaching instruments when animals can be captured. Holes should be cut using a coring device that removes tissue. Circulatory "hot spots" should be avoided. These can be located by using infrared thermography of the area or probing with a hypodermic needle prior to coring. Bolts made of Delrin or similar plastics should be used instead of metal and should be held on by steel or magnesium nuts isolated from

the skin. Threaded ends of the rods should not touch the tissue. Multiple-bolt mounts should be used in place of mounts using two bolts.

5. Single attachment sites should be used whenever possible. When needed (*i.e.*, for heart rate monitoring), multiple attachments should be placed in line to reduce drag; measurement of the drag should be made.
6. If used, saddles should be made of PCS, Teflon, or other materials resistent to biological fouling. These may be heat-formed for custom shape, and fitted to the fin or ridge with neoprene or open cell foam to reduce chafing. Tightness is critical, as tight saddles may cause pressure necrosis, while loose saddles may cause tissue damage at the attachment holes.
7. Instruments should not be deployed by mounts on the caudal peduncle, except for manatees, as they cause excessive drag and abrasion due to fluke movement.
8. Harnesses should not be used to attach instruments to cetaceans as they are difficult to fit and have been shown to increase drag, respiration rates and blood lactate levels in swimming bottlenose dolphins.
9. Presently available epoxies and adhesives should not be used on cetaceans, except possibly on barnacles that some species carry; research on new adhesives should not be inhibited however.
10. The basic tag should include emersion, pressure, and temperature sensors, which need little or no development.
11. Veterinarians are valuable as consultants during capture and tagging operations; however, their involvement should not be considered mandatory for tagging operations that do not involve capture.
12. Researchers wishing to gain experience with a particular attachment system or species should learn from others already active in the field.

GENERAL

1. Efforts should be made to maintain the animals that are presently scheduled to be moved from the Naval Ocean Systems Center's Hawaii Laboratory so that they are available for benign testing of sensors. If this is impossible, other arrangements should be made to allow continued access to other animals for such testing and development. Oceanaria should be encouraged to recognize their responsibility for assisting in such testing as part of their stewardship of captive marine mammals.
2. The suggested criteria listed herein should be used by applicants for research permits and the NMFS permit office to help judge the merit of research permit applications. The worthiness of permit applications should continue to be judged by peer review, preferably by experienced wildlife researchers.
3. To facilitate the permit process, the applicant should supply the following information: (a) demonstrated past experience with capturing and tagging of marine mammals, (b) evidence of thorough knowledge of the tagging system to be used, and (c) demonstrated experience with the particular tagging system to be covered by the permit, or consultation with those who are experienced.
4. Researchers should collect and store tissue samples obtained during cetacean handling (*e.g.*, coring for dorsal mounts). A list of tissue banks and other laboratories interested in marine mammal tissues should be compiled, and these groups should be notified when tissue becomes available.
5. The editors of *Marine Mammal Science* should be formally asked to accept and publish papers on capture and attachment techniques.
6. Integration of marine mammal behavior with oceanic data such as bathymetry, climate, current, acoustic profiles, primary productivity, fisheries, *etc.*, and other aspects of the species is needed. A list of appropriate data sets, with their availability and format, should be compiled, and a study made of what software/hardware is available and most appropriate for displaying and cross-correlating behavior data with oceanic datasets.
7. A working group should be convened to examine current data logger techniques and resulting behavior datasets to assess the applicability of these techniques to all marine mammals and to formalize definitions of parameters for inter-study comparison. Interaction between and within groups analyzing data and groups developing data logger technology should be promoted.
8. Repositories for works describing both successful and unsuccessful attempts to capture and attach instruments to marine mammals should be established at the National Marine Mammal Laboratory in Seattle and at the Marine Mammal Commission in Washington, D.C. These should function as lending libraries.

INTRODUCTION

Use of Tags in Marine Mammal Research and Management

Carol Fairfield, Robert Hofman, and Steven Swartz

There are a number of marine mammal conservation issues, as well as questions of basic scientific interest, that require location and corollary behavioral and environmental data to resolve. Traditionally, researchers have attempted to obtain such data by conducting surveys and behavioral observations from ships and airplanes. These are expensive to operate and, in cases involving widely disbursed, far-ranging or highly migratory species, many years and many thousands of ship-days and aircraft flight-hours are required to obtain sufficiently reliable data. The problem is further compounded by the fact that marine mammals spend only short periods of time at the ocean surface where they can be seen. In addition, weather conditions often may preclude both surveys and behavioral observations.

Radio, sonic and satellite-linked radio tags have been used with varying degrees of success to study marine mammals since the 1960s. The utility of this methodology to study marine mammals has become increasingly apparent. If the attachment problem can be overcome, needed location and corollary behavior and environmental data could be obtained much more cost-effectively using satellite-linked radio tags, recoverable data recorders, acoustic tags and other largely available or conceptualized technology. The utility and cost-effectiveness of such technology have been well demonstrated in cases where long-term attachment is not necessary or the attachment problems have been overcome (Fedak *et al.* 1983, 1988; Hindell *et al.* 1988; Goodyear 1990; Le Boeuf *et al.* 1988, 1989; Rathbun *et al.* 1990; Mate 1990; and Boyd *et al.* 1991). Further, use of remote sensing and radio telemetry techniques permits collection of data in remote areas, at all times of the day, largely without the constraints imposed by weather and expensive logistic support.

Some of the topics that can be addressed through tagging and tracking studies include, but are not limited to:

- seasonal distribution and habitat use and relation to oceanographic features
- stock discreteness
- migratory routes
- diurnal and seasonal activity patterns
- identification of critical areas (*i.e.*, feeding, calving, nursing areas)
- foraging ecology
- reproductive biology
- behavioral and physiological responses to environmental variability and anthropogenic activities (*i.e.*, entanglement issues and responses to vessels, noise, and industry activities)

It is possible, in some cases, that animals could be killed or injured, or that attachment sites might become infected in the course of studies using specialized instrumentation. The risks are minimal and, even in cases involving highly endangered species, the benefits of the resulting data, with regard to identifying and determining how to avoid or minimize conservation problems, far outweigh the risks. In many cases, the risks to the animal as well as the researcher will be less than attempting to gather the same information using traditional ship and air observation techniques that require close approaches and/or following animals for long periods of time.

The state of the technology is very dynamic and in need of periodic review to assess the capabilities and limitations that are present at any given time. One such review was conducted in February 1987 through a workshop sponsored by the Minerals Management Service (MMS) and hosted by the Marine Mammal Commission (MMC) to assess the systems available, or which could be developed in the coming years, for tracking large cetaceans. The difficulties encountered in past tagging and tracking efforts were reviewed, as were the capabilities and constraints of the Service Argos system. Alternatives to satellite-linked tracking that were discussed included conventional HF and VHF tags, passive and acoustic tracking, high-altitude aerial photography and satellite imagery, visual techniques including photo-identification, and recoverable archival tags.

The following conclusions resulted from that workshop (Montgomery 1987):

- available technology was adequate for at least short-term studies (hours to weeks), with dart-type projectile and barnacle-type tags;
- only superficial injuries or temporary alterations in behavior had been recorded although long-term studies on the effects on behavior or survival were limited; and
- a high-frequency, high-power output transmitter for use with the Service Argos system could not fit into the available projectile tags.

A series of field studies were recommended by the workshop participants to resolve these limitations, which included studies to:

1. develop a Service Argos certifiable transmitter that could be configured to fit into the existing or modified projectile tags;
2. develop systems to attach barnacle-type tags to whales at distances beyond 5 m;
3. determine retention times and long-term effects of barnacle and capsule tags on the behavior and survival of various species of individually identifiable cetaceans.

As a result of these recommendations, the MMS sponsored a multi-year study to further develop a satellite-linked tag to monitor the migratory patterns and habitat use of marine mammals. During this ongoing study, right and bowhead whales have been tagged and tracked for more than five weeks. MMS also sponsored an unsolicited proposal to develop and test a capsule tag on humpback whales, which were tracked for over four weeks. Development of sonic tags, and tags attached to the dorsal fins of medium-sized or small whales, was also undertaken through other funding by several researchers.

Two events occurred in 1988 and 1991 that further emphasized the potential use of satellite-linked tags to study the movements and behaviors of cetaceans. In 1988, the Marine Mammal Protection Act was amended to allow for a small take of marine mammals incidental to fishing and oil and gas activities, when a negligible impact could be demonstrated, though a monitoring program was required to verify such a negligible impact.

In 1991, the Heard Island Feasibility Test was conducted off Heard Island in the southern Indian Ocean. It was aimed at monitoring global warming by measuring ocean temperature changes as a function of acoustic travel times across ocean basins. The signal used during tests included a variety of wave and phase coded signals centered at 57 Hz, with band widths of 10 Hz or less, and maximum signal strength of 219 db. As a result of the Navy's request for a marine mammal scientific research permit from the National Marine Fisheries Service (NMFS), an agreement was reached that would extend research to investigate the impact of acoustic energy on marine mammals. As the permitting agency, NMFS also recognized the need to pursue the use of advanced technology to solve basic biological questions. This technology will help establish optimum sustainable population (OSP) levels and the possible biological removal (PBR) factor that is required for management.

Based on this common interest in continuing development of tagging and tracking technology for the study of marine mammals, NMFS, MMS, and the Office of Naval Research (ONR) chose to collaborate to more effectively achieve this goal. The first collaborative activity was to organize and sponsor a workshop to assess the present state of the tagging and tracking technology. Researchers and industry involved in the development and manufacture of satellite technology to study birds, terrestrial mammals, and physical oceanographic properties, as well as marine mammals, were invited to participate in this workshop.

Workshop Arrangements

The Workshop on Tagging and Tracking Technology was held February 11-13, 1992, at Airlie House, Warrenton, Virginia. The meeting was organized by ONR, MMS, NMFS, and MMC. A copy of the workshop agenda is appended as Attachment A.

Participants in the workshop included researchers from the United States, Great Britain, Canada, Norway, and Japan with direct experience in tagging and tracking marine and terrestrial species. Also participating were representatives of engineering and consulting firms involved in developing radio tags, along with representatives of the sponsoring organizations and the U.S. Fish and Wildlife Service and the British Sea Mammal Research Unit. A list of workshop participants is provided as Attachment B.

Workshop Objectives

The overall objectives of the workshop were to:

1. Determine the state of the art with respect to:
   a. instrumentation and sensors
   b. attachment techniques
   c. data acquisition;
2. Identify the problems and deficiencies in existing technologies that must be overcome to effectively meet users interests and requirements;
3. Identify what needs to be done to overcome the problems and provide estimates of how long this is likely to take and how much is it likely to cost to accomplish the identified needs; and

4. Describe user interests, needs, and requirements.

Workshop Organization

The workshop was organized by a steering committee composed of representatives of the sponsoring agencies. The first day of the meeting was devoted to a general review of the state-of-the-art with regard to data loggers, satellite, radio-frequency (RF) and acoustic tags; attachment devices and methods, both on captive and free-ranging animals; and data recovery and analysis. Summaries of these presentations are included in the next section of this report.

During the second day of the workshop, participants separated into three working groups: (1) Tag Delivery, Attachment and Release Systems; (2) Instrumentation; and (3) Data Transmission and Analysis. On the final day of the meeting, the three working groups presented their conclusions for discussion by the workshop as a whole. The reports of the working groups are included in Part III of this report.

II. WORKSHOP PRESENTATIONS

Overview of Data Loggers

Presented by
Roger L. Gentry

BACKGROUND

This report reviews digital instruments presently being used or being developed to measure aspects of diving in marine vertebrates. Because the field is moving away from use of analog instruments, they are not included. Neither does this review address the more technical aspects of data loggers.

The review is based on correspondence with innovators in several parts of the world who are marketing or building oceanographic instruments or data loggers for use with marine mammals, birds or turtles. It was not possible to contact everyone who is making such instruments although this report covers a reasonable cross section of available gear. The participation of those who contributed to this review is much appreciated.

INTRODUCTION

This field has changed substantially since it began some 20 years ago. In the mid-1970s, instruments were improvised, crude, but workable systems. These were generally custom-made for a single species by a single innovator and were available to a very restricted group of users. With the advent of digital technology, instruments became powerful and sophisticated; the availability of user programming also made them more flexible. Instruments were designed to measure a standard array of parameters, regardless of the species on which they were used. Commercial manufacture and user-friendly software made them available to a very broad group of users.

The scientific community is now seeing a period of almost exponential growth in instrumentation for recording dive data on higher marine vertebrates. The number of parameters that can be measured is increasing rapidly, and the precision of measurement of basic parameters is improving. The size of instruments has dropped to 35 to 50 g, which has increased the number of species to which these devices can be attached. The sampling rate is limited only to the extent that rates of one per second are limiting for a given application. With the recent advent of the 512 K byte memory chip, the size of available memory ceases to be a problem. From the user's standpoint, there is no end in sight to the improvements available in modern data loggers.

This advancement has had great benefits. No longer is the measurement of diving an esoteric exercise practiced by a very few researchers; instead, it has nearly become a standard part of field studies. Use of common instrumentation has led to standardized measurements, thereby allowing for comparisons of performance among species. And finally, these improved capabilities have helped blur the distinctions among the formerly discrete fields of diving behavior, ecology and physiology and helped create what some consider a new field: foraging ecology. As might be expected, there is a down-side to this shift. In many instances, new instruments are so expensive (nearly $5,000 U.S. for some models) that institutional support may be needed for field research. In addition, the quantity of data produced by these instruments is so large that analysis might require use of mainframe computers, resulting in additional need for institutional support. And finally, there is a danger that, because of the high quality of new off-the-shelf instruments, some users may come to rely on them, not questioning or even understanding the instrument's calibrating features, such as the zero offset correction for depth. In the worst possible case, the ready availability of hardware and software may tend to suppress innovations in the field.

CURRENTLY AVAILABLE INSTRUMENTATION

Sensors

Initially, Gerry Kooyman devised an analog instrument that measured depth and time for single dives. A later version measured multiple dives. This second instrument acted like an accelerometer and gave a trace for activity level that was referable to sleeping and grooming. At that point, digital data loggers were introduced; these could store depth (as a histogram) but not time. In the mid- to late 1980s, digital units were introduced that could measure swim velocity as well as time and depth. Soon after, environmental temperature and light level were added to the list of measurable parameters. In the late 1980s, Roger Hill used light level data in complex calculations to make position estimates (latitude from day length, longitude from local apparent noon). At about the same time, several different researchers were coupling units that measured only time and depth with Service Argos satellite transmitters. Likewise, several teams of investigators, led by Gerry Kooyman and Paul Ponganis, devised various means of measuring heart rate. On the physiological side, units are now available to measure body temperature in addition to environmental temperature, oxygen and pH (as an estimate of PCO2). Most recently, Roger Hill has linked the data logger to a radio frequency beacon so that the investigator can locate it at critical periods.

In the foreseeable future, many new parameters will be measurable. At least two investigators are working independently to produce a unit to measure sea water conductivity as a means of estimating salinity. Two other investigators are trying to develop mechanisms to measure prey capture. Feasibility studies are being done on incorporating Global Positioning System (GPS) calculations into data loggers to improve position estimates. A flux compass to measure movements in three dimensions is now one or two years away. A commercial unit to measure swim velocity could become a reality within six months. Finally, one team is working on heart rate devices that are to be implanted, and another is working on communicating with data loggers by fiber optics instead of wire communications.

While these new sensors and peripheral features are being developed, improvements are being made in some of the older capabilities. One investigator is working on a nonmechanical means of measuring swim velocity. Another is looking into measuring depth through a fiber optic means that offer low power requirements and is not sensitive to temperature changes. Finally, some changes are being made in software. The British Antarctic Survey is developing a program for mainframe computers that gives the user better control over data output and access to all stored data. The Max Planck Institute is developing a graphics program that gives the user unlimited access to graphic data on screen for plotting, printing and writing to disk.

Memory

It is doubtful that anyone's work currently is limited by memory. In 1985 velocity units featuring 8 K of memory were the latest innovation. Presently, Wildlife Computers can produce a unit with 2 megabytes of memory without changing the configuration of the 130-g package. More memory could be added at a slight sacrifice in package size. With such large memories, there is a possibility of collecting much more data than are actually needed, which Harry Burton has called "data poisoning."

Price

The present prices of ready-to-use data loggers range from about $500 to $5,000, depending on the options, memory size and packaging.

Central Processing Units

Most data loggers available today use a microprocessor as the central processing unit. Of the 14 instruments surveyed in this review, 12 were microprocessor-based. The advantage of microprocessors is their flexibility; they can be programmed to monitor various sensors at varying sampling rates and schedules.

One investigator, Marcus Horning of the Max Planck Institute, has developed a data logger based on electronically programmable logic devices, or EPLDs. The unit, soon to be available commercially, is basically an array of logic cells programmed to sample set parameters at a few preselected sampling rates. Horning claims that the low power requirement, more fail-safe programming, and lower cost of his units almost defines what might be called a "Volkswagen" tag, that is, a basic, off-the-shelf, inexpensive tag that is adaptable to a number of research needs.

Yasuhiko Naito of Japan's Antarctic Program is leading the development of a data logger that is built around a custom-made circuit and has no CPU.

DATA LOGGERS IN USE

Generic data loggers are available with a CPU and memory chip to which the user can add sensors as needed. The *Tattletale* is one such unit. Their big advantage is their low cost. Some engineers believe that these units are too large and power-hungry, and their software is too crude to compete seriously with custom-tailored units. Don Croll, who is presently using a *Tattletale* to measure swim velocity on Antarctic fur seals, reports that they are functioning quite well.

Wildlife Computers is the largest manufacturer of data loggers made specifically for marine vertebrates. The company has four models available, two of which are linked to satellite beacons. The *Mark 3e* unit measures depth, temperature, light and position as described above. It has eight data channels, up to 2 megabytes of memory, and weighs about 130 g. It comes in pressure housings tested to 1700 m. Communication is by means of a wire, and operating lifetime is unlimited because the batteries can be changed. The *Mark 5* unit measures the same parameters, has three data channels and up to 512 kilobytes of memory. It weighs 50 g and is potted in electrical resin. The operating life of the batteries is about 10 yr. A new model data logger, the *Mark 6*, will be available in the near future. It uses the circuitry from the *Mark 5* to measure swim velocity. Wildlife Computers offers two satellite-linked TDRs (SLTDRs), both of which transmit a histogram of dive depth and duration only, using a *Telonics* transmitter. The models differ mainly in their power output (1 and 0.5 watts) and weight (1.1 and 0.5 kg).

Platypus Engineering in Tasmania offers two data loggers that are similar to those available from Wildlife Computers. Officials of Platypus could not be contacted, but Harry Burton, a user of the company's data loggers, provided information. Platypus Engineering produces a small unit, developed for use on Adelie penguins, that measures time, depth, and swim velocity by means of a paddlewheel arrangement. Burton states that the instruments are very reliable although the software is not as sophisticated as that produced by Wildlife Computers. The company also makes a larger unit, comparable to Wildlife Computers' *Mark 3e*, that measures time, depth, temperature and light level. In 1993, after eight years of development, the firm expects to add sea water conductivity (measured by inductive sensing) to the list of available sensors. Burton reports that these units are less expensive than the Mark 3e, but are less sophisticated in their software, especially that used to analyze the light measurements. Burton also said Platypus Engineering was developing a "Volkswagen" tag, but he had no details.

In the next year or two, Marcus Horning of the Max Planck Institute also intends to commercially produce the data logger described earlier. The unit will measure time at sea, velocity and depth.

Several groups of investigators are building instruments for their own use. Gerry Kooyman and Paul Ponganis have developed a unit to take physiological measurements. Their unit has two temperature channels plus special circuitry for measuring heart rate and oxygen levels in blood or muscle. The data loggers do not have especially good software, nor are they especially thrifty on power. These units have been built because none of the commercially available units have interfaces for the required sensors.

Daniel Konnoff and Don Croll are using a potted data logger that measures swim velocity and depth. Weighing only 35 g, it is small enough for use on murres. The units have a small (28 K) memory, but they use it efficiently.

The British Antarctic Survey, in partnership with Tony Woakes and Pat Butler of Birmingham

University, have developed a heart rate recorder for birds that can be implanted or mounted externally. It uses cross-thorax electrodes and, storing 30-second summaries of heart rate, has enough memory for several weeks. Researchers have used it successfully on otariids, and intend to couple the recorder with a conventional TDR in the future. The Survey is also developing a satellite-linked TDR using a Wildlife Computers *Mark 5* data logger coupled with a *Toyocom 2038 PTT*.

The Sea Mammal Research Unit is also making a SLTDR that measures depth and velocity. However, this unit is not archival, and will be discussed in more detail in the overview of satellite tags.

Yasuhiko Naito is conducting research and development on a complex new data logger that could be produced in the near future. Also, Tim Whitmore is working toward modifying aircraft GPS hardware and software so that GPS positions could be incorporated into existing data loggers as an input channel.

THE VOLKSWAGEN/ROLLS ROYCE DEBATE

Investigators in the field have debated the advantages and disadvantages of the Volkswagen, or common data logger, and the more sophisticated, customized Rolls Royce version. The opposing philosophies in this debate have been articulated by Marcus Horning and Harry Burton. Horning points out the value of having available a fail-safe, reliable, small unit that is inexpensive enough to be used on large numbers of animals of any size and that produces data in a fairly raw form. He sees the unit's inflexibility as an advantage, noting the number of investigators who have failed to get data from a deployment because of an error in the initial programming. As noted earlier, Horning intends to produce such a tag in the future, and Platypus Engineering may also have such a unit in preparation. Wildlife Computers reports that, if demand warrants it, the company could produce its Mark 5 unit in a user-assembled kit at an attractive price. However, the assembler would need access to calibrating equipment.

On the other hand, Burton points out that focusing on cost of the units is misleading. He believes that institutions and researchers compete through data output, not cost. From that standpoint, a large, flexible data logger may produce far more data proportionate to its cost than could a Volkswagen-type unit. Burton believes that the desired trend should be toward obtaining more and more complex data and that aiming toward producing more simple data is misdirected effort.

PRESSING NEEDS

The most pressing need today may be in software. Standardized software has unified our field, a benefit that none of us can deny. But increasingly, investigators want more open access to the raw data, and more control over their own output. This is made evident by the British Antarctic Surveys's work on developing a mainframe program and the graphics program being developed by the Max Planck Institute. Both are attempts to maximize what investigators get out of present data loggers. Thus, the trend may be not toward more customized programs, but toward more generic ones.

In regard to sensors, there are as many opinions about what is needed as there are investigators. Looking at the field as a whole, perhaps more investigators would benefit from development of a standard way of measuring velocity than from any other single sensor. Many would use a sensor to measure activity level as well. Once there is a means for measuring prey capture events, researchers can begin to formalize studies by applying foraging theory to the data sets. Probably a smaller number of investigators would welcome availability of GPS data for more precise location-finding and a flux compass to reveal three-dimensional use of space. Physiological data, such as heart rate/metabolic rate, body temperature, and blood gasses, are so complex and variable that it is difficult for anyone except a specialist to interpret them. Therefore, the capability to measure these parameters will be of greatest value to a small number of investigators, although heart rate may be of interest to a broad audience as a potential index of stress once its veracity as an index is proven.

To date, the unsurmountable problem with data loggers, in fact the major bottleneck to progress in the field, is that their power is largely wasted unless the units can be retrieved. Even the smallest microprocessor on the market can handle vastly more data than can be accommodated by present satellite telemetry. The success achieved in describing the diving characteristics of any species of marine vertebrate is directly traceable to the that species' behavior relative to instrument retrieval; that is, how easy the species is to catch, whether it occurs in predictable locations, and whether it has hair or feathers for attachment. If the goal is to understand the pelagic lives of marine vertebrates by obtaining complex data collected in remote parts of the ocean throughout the year, then there must be a major breakthrough in transmitting data.

Overview of Satellite Tags for Cetaceans

Presented by

Jeffrey Goodyear, Anthony Martin, William Watkins, and Bruce R. Mate

Goodyear reported on success in tracking humpback whales for more than four weeks using a projectile-attached satellite tag. He developed the tag, which incorporates a *Telonics ST-6 PTT*, for the purpose of identifying the migration routes, migration rates, and exchange between feeding grounds of right whales tagged in the Bay of Fundy. Poor weather and lack of whales precluded use of the tag on right whales. Instead they were applied to humpback whales off Massachusetts in May-June 1991, on which location, water temperatures and various dive parameters were measured.

The humpbacks were first tagged with simulated satellite tags in order to test the new satellite tag housing, attachment anchor and deployment systems. The simulated satellite tags contained sonic depth-of-dive and radio transmitters to allow whales to be tracked from a small vessel. These observations indicated that the tag systems worked well and that functional satellite tags could be applied. The simulated satellite tags also provided the first-ever depth-of-dive profiles of humpback whales on their feeding grounds.

The prototype tags worked well, but several modifications will be made to increase attachment longevity. Specifically, weight will be reduced by about 50 percent (to about 180 g), length reduced to about 16 cm, and the mechanism connecting the anchor to the tag body will be modified. Other improvements will be the addition of more sensors, especially to record dive depths. These updated versions are expected to remain attached to whales for several months; 6 to 9 months battery power will be provided.

With limited training, these tags and the tagging system are practical for general use by the scientific community. The system is available to the scientific community for purchase by special arrangement.

Tony Martin summarized his work with a saddle pack and two plastic sutures on beluga whales. In collaboration with the Department of Fisheries and Oceans, Canada, the Sea Mammal Research Unit has been applying satellite telemetry techniques to the study of belugas since 1988 and to narwhals since 1991. To date, 17 beluga and 3 narwhals have been equipped with back-mounted transmitters, with a maximum longevity of 75 days.

The transmitters are housed in pressure casings of anodized aluminum and attached by means of a saddle of flexible PVC-impregnated material and nylon pins to the fibrous dorsal ridge of the animal. Emergence, swim-speed and pressure sensors are fitted as standard. The units are built in-house, using RF boards from Toyocom, Japan, and the same basic design has been successfully deployed on three pinniped and one otariid species in addition to the two cetacean species. The improved longevity of the units when used on seals (up to 250 days) indicates that the transmitters are falling off the whales or otherwise failing before battery life is exhausted. During the 1992 research season, attention will be focused on improved attachment methods. William Watkins reported that a small new *Argos PTT* transmitter design has been adapted to fit the whale tagging system successfully used by researchers at Wood Hole Oceanographic Institution. This is the only transmitter found that could be used in the restricted configuration of the Woods Hole tag (1.7 cm internal diameter by 6 cm). The unit is an adaptation of those currently used for tracking eagles and other birds. Ballistic tests show that the electronics are not affected by the accelerations and decelerations of delivery and attachment, the antenna design is being adapted to the attachment requirements, telemetry inputs are being designed, and initial field tests are in preparation. The pace of this development depends on support. A satellite tag in this ballistic configuration will allow its use in the open sea on all of the large whales. Because it has the same delivery and attachment system as the other Woods Hole whale tags (HF radio tag and acoustic sonar transponder tag), the satellite tag will be ready to use immediately without extended attachment tests. (This attachment system has been used successfully for work on six species of whales to date.)

Bruce Mate has been successful in tracking a pilot whale for 95 days using a dorsal fin saddle pack and plastic pins and also tracking right whales in the North Atlantic with a projectile tag (*Telonics ST-6* packaged by Oregon State University). These tags have generally recorded discrete and summary information on dive durations and temperatures. A few have also begun measuring depth information.

Advanced tags are being developed by Mate, Yasuhiko Naito, Roger Hill, and the Sea Mammal Research Unit to record more sophisticated depth data. Several investigators and manufacturers are moving toward miniaturization of location-only tags and the development of additional physiological and oceanographic sensors. There appears to be little opportunity for the development of new power sources but there is more that can be done to conserve power by coordinating transmissions with satellite overpasses. At the present time, the idea of using the receiver to determine when the satellite will be overhead appears inefficient in terms of space and energy, and it is more likely that timing of transmissions will be controlled by sophisticated programming of onboard microprocessors or recognition of day length periods to coincide transmissions with synchronous orbits of the satellites.

There are several substantial problems that investigators are approaching in different ways. Most significant is the means of attachment. Attachment methods are discussed elsewhere in this report, but it is important to note that the only experiment in which the power supply was completely exhausted is the 1987 work by Mate *et al.* in which the tag was attached to the dorsal fin of a pilot whale. In general, electronic packages currently are functioning well and do not present a significant reliability problem. Packaging, however, is a concern when working with animals that dive to great depths, and some investigators have had problems with leaking in packages attached to pinnipeds. The substantial advantage that pinnipeds offer in application of the tag to the pelage with epoxy cannot be duplicated with cetaceans, nor do cetaceans return to tagging sites for subsequent recapture and recovery of larger data storage devices.

A second problem area concerns transmissions. The Argos system, limited to a 256-bit message during a 1-second period under standard protocol transmissions, may only be heard once per minute per identification (ID) code. For experiments with marine mammals, Service Argos has shortened this to once every 40 seconds, and some investigators have effectively achieved a higher baud rate by using multiple ID codes and sending sequential messages during long surface times. There are two problems with this: (1) Argos charges for every day an ID code is acquired through its system, and (2) this puts a strain on small battery supplies dealing with consecutive transmissions. It is conceivable that there would be experiments, however, where a short period of operation and multiple ID codes would be an ideal strategy to relay the results of perhaps more physiologically oriented experiments. Another application might be to send bursts of information after reasonably long intervals without transmission. In many cases, however, the primary piece of information desired is long-term movement data and it may be desirable to stick to a single ID code, the shortest feasible message (340 milliseconds) in order to obtain the longest possible longevity for the transmitter. Several manufacturers appear ready to deliver such a product with an approximate 30 to 70 percent savings over the size of the present transmitter sub-assemblies.

A third difficulty arises from the 15 percent error rate typically experienced by Argos users. This poses a major problem for those who are sending unique messages at each transmission. If data is repeated, errors may easily be sorted out when more than a single message is acquired. However, for discrete messages, it is advisable to include error detection or error correction codes so that only reliable data is used in analyses.

In general, the researchers are beginning to achieve significant results with Argos transmitters on small and large cetaceans. The value of this information is exceedingly high and in some cases there may be no alternative means of acquiring it. In most cases for animals that range widely or travel to unknown habitats, it may be the only cost-effective means of tracking multiple animals, given the alternatives of close range monitoring for acoustic and conventional telemetry (manpower, boat logistics, weather, safety, *etc.*). The attraction to the field is likely to be enormous and several cautions are justified. The results tend to emphasize the value of the work and researchers tend to (in limited time and space presentations) emphasize those aspects of the project that worked smoothly. The overall impression is that the techniques that work are easy but the researchers agree that they are not. Most of the successful techniques have been developed over a considerable period of time and successful investigators are concerned that failed attempts by inexperienced workers could reflect badly on the field in general and specifically on the developer of the techniques being emulated.

More success will be achieved in the future with smaller, lighter, less expensive, and more energy efficient hardware and more sophisticated means of data compression, error detection and analysis methodologies. From the results of successful studies to date, it is apparent that correlation with physical oceanographic information and meteorological data is desirable for explaining many of the movements and dive patterns of tagged whales. Because of the expense of the hardware, data analysis and computing power to bring in tangentially related data, it appears that large-scale studies will be limited to institutions that can provide infrastructure support. Several investigators have indicated a willingness to work in collaborative relationships with those interested in tracking a variety of species in different geographic areas. This type of collaboration, along with graduate student development and apprenticeship strategies, are potential methods of training additional personnel.

There will probably always be a need for "simple tracking tags" and more sophisticated sensor-rich tags for specific experiments. Users of the systems would do well to use appropriate levels of technology to keep the size and costs down to the level necessary to achieve goals. Alternative systems to Argos have been explored and are reviewed elsewhere in this document. At the present time, Argos is the only system available to civilians capable of locating transmitters anywhere on Earth, and thus represents a substantial resource. This system is committed to staying operational into the next century. While there have been successful experiments using LORAN-C or GPS relayed by VHF in terrestrial studies, the marine equivalents have not been demonstrated at the present time and there may be substantial technical challenges to getting these operational in the very near term. These include size, updating of ephemeral information and energy requirements. These are problems that can, no doubt, be overcome but are not insignificant. In general, the researchers using Service Argos agree that the cost of data recovery is cheap and that, although the baud rates are limiting, they can be used effectively to provide an enormous amount of information for cetaceans. While there has been some discussion that development of tags should not necessarily be directed at endangered species as "first targets of application," the reality is that only endangered species will receive adequate attention from funding agencies for the application of this type of technology. Further, it is the consensus among investigators and consulting veterinarians that this form of research presents very little risk to these animals.

Overview of Acoustic Telemetry

Presented by
Mike Fedak and William Watkins

The study of the movements, behavior and physiology of marine mammals at sea requires the effective use of telemetry or recoverable recording devices. By combining various techniques, it is often possible to overcome the limitations of a single approach more easily than it would be to improve the capabilities of a single technique. The combination of VHF and acoustic telemetry with direct tracking of marine mammals can provide information that is difficult or impossible to obtain using less direct methods. It also provides information without which other techniques (such as satellite telemetry and recoverable recording devices) could not be as effective as they might otherwise be.

In order to provide answers to a set of interrelated questions about the movements, foraging, energetics and physiology of seals in relation to their environment, the Sea Mammal Research Unit of the Natural Environment Research Council (U.K.) has combined three approaches, providing information at a variety of levels, each with a set of advantages and limitations. These include simple VHF transmitters with remote automatic direction finding recording stations placed along coasts, real-time tracking with acoustic and VHF transmitters, and satellite-relayed data loggers.

VHF transmitters and automatic recording stations provide a low-cost method of studying coastal movements and vanishing bearings around haulout areas and along coasts. Because it uses inexpensive low-power transmitters and untended automatic stations, large numbers of animals can be studied for extended periods. The information provided lacks detail and range is limited.

Because they transmit through sea water, acoustic transmitters, can provide detailed real-time information about behavior, feeding success and physiology. Animals have been equipped with four transmitters simultaneously. Three acoustic transmitters send combined depth and speed information, stomach temperature (to monitor ingestion) and ECG. A VHF transmitter indicates when animals are at the surface and allows for locating animals at a distance *via* a specially built automatic direction finder. A boat is equipped with appropriate recording gear and follows the animal, allowing direct observation of prevailing biological and oceanographic conditions. Highly detailed information can thus be provided in context, that is in relation to the animal's immediate environment at the time of measurement. The method is costly in terms of time, money, and personnel and is dependent on weather and location. Conditions of geography and season may limit where and when work can be undertaken, and cost and time constraints limit the number of animals studied and the duration of the observation period.

Satellite-relayed data loggers overcome some of these difficulties. Once equipment is attached, data can be received from any location in any weather for as long as the devices last. Limitations on the data transmission rate require that some processing be done in the data logger; therefore, less detail is available. Given present technological limitations, tags are expensive and relatively large, limiting the species on which they can be used and the number that can be deployed. Field and logistic costs are lower than for real-time tracking and the potential biases that might result from logistic constraints are diminished. Real-time information about the animal's immediate environment, its interactions with other species, *etc.*, may be lost or difficult to obtain.

To some extent, these limitations are inherent in the techniques themselves and can best be overcome by combining techniques, rather than engineering any one to accomplish all needs.

The approach taken by the Sea Mammal Research Unit in studying seals using real-time acoustic and VHF telemetry includes the design of tags, receiving and data logging equipment and the range of platforms on which they have been used. Data from work on grey seals provides an example of what can be accomplished, both in terms of the type of information available and the level of detail possible. There is significant value to the "analogue" nature of the data stream possible with real-time telemetry for providing important clues to the reliability of the data being received, particularly when there are no clear expectations as to the patterns to be expected.

These data have proven crucial to understanding the foraging tactics (both behavioral and physiological) and the ability to design data loggers with efficient data compression techniques that provide information via satellite relay systems. Information collected in this way has also been essential in interpreting data obtained remotely, both by satellite and automatic VHF recording stations.

In general, any effective tracking system must provide geographical location and depth. That is, it must provide some sort of three-dimensional locating capability. This follows from the fact that oceanographic characteristics are always mapped in three dimensions and the movements of the animals are very much three dimensional. Since these characteristics and locations change with time, the time dimension is also crucial and therefore data should be presented in a way that provides the best possible time resolution of the three-dimensional data within the constraints imposed by transmission or storage. The need for extremely precise geographic location resolution at the surface is relaxed somewhat in long- and deep-diving species by the fact that for most marine mammals, time at the surface is solely for breathing with most foraging activity spent at some distance vertically and perhaps horizontally from their surface position.

Watkins reported on recent studies of sperm whales using acoustic transponder tags to provide consistent tracking of their underwater activities. Long series of dive profiles were monitored, with depth and underwater locations measured at intervals of a few seconds. These tags are interrogated at 30 kHz, and responded with 36 kHz primary and 32 kHz telemetry pulses. A 360-degree sonar was used to track the tag signals, providing reliable direction, distance, and slant angle to the tags. Distance to the tag and its depth was also indicated by digital telemetry display, and a three-dimensional hydrophone array provided tracking of whale and tag signals, as well as direct association of whale vocalizations with the tagged whales. The transponder tag used the same Woods Hole whale tag delivery and attachment system developed for the HF radio tag (and planned also for use with the satellite tag). All sounds produced by the acoustic tag system were apparently ignored by the whales. Even so, it is strongly urged that no sound source ever be used on marine mammals unless it is always in the control of the investigator — so it can be used sparingly or not at all if the animal exhibits any response to the signals.

Overview of Tag Delivery and Longevity

Presented by

William Watkins, Bruce Mate and William Medway

Watkins reported on Woods Hole Oceanographic Institution's whale tag delivery and attachment system. It was developed for the HF radio tag, has been used for the acoustic transponder tag, and it is planned for use with the satellite tag. The HF radio tag has been used extensively for more than 15 years, and it has allowed consistent automatic (ADF) ship tracking to 30 km, and to 300 km from aircraft.

The tag is launched from a special shoulder piece by selected blends of gunpowder to accelerate the tag assembly over the length of the barrel. During the tag's flight at a velocity of 60 m/sec, it is attached to a push-rod with retrieval line, and the push-rod is released on attachment and pulled back. The tag is implanted in the surface tissues of the whale's back, from the rear, at a low angle of 30 degrees or less (perpendicular blubber penetration usually about 4 cm). A special point prevents ricochet during low-angle attachment, a pair of short toggles helps retain the tag, and the epidermal tissues close tightly over the tag with only the antenna (radio and satellite) or transducer module (acoustic transponder) external. The backward, low-angle orientation and low volume of external tag components reduce water drag. This system permits open-ocean tagging and has successfully been used in studies of six species of whales. Examples of the success of this system include the Iceland to Greenland track of a double-tagged fin whale, the tracks of bowhead whales from the Canadian Arctic across Alaska into the Chukchi Sea, or the underwater tracks of dive profiles of sperm whales in the Caribbean.

Bruce Mate reported on the form of remote attachment used for the Oregon State University tags. Investigators chose a 150-lb compound crossbow as a compromise between sufficient power to achieve full deployment and safety concerns for both the animal and the tagging crew. Because researchers work primarily from smaller vessels (less than 60 ft), it is necessary to approach reasonably close to animals in order to achieve a good vertical antenna orientation on the midline of the exposed portion of the whale's back. With skilled personnel, close approaches have not been difficult and, in fact, the crew has successfully tagged at least two animals per day during research cruises. It is not believed that the approaches to the animals have constituted undue harassment. In fact, little reaction has been observed, either to the boat or the tagging procedure. Whales have continued to remain approachable after tagging and some have resumed sleeping patterns within minutes after tagging. Several investigators have observed whales reacting when objects are dropped or propelled into the water without hitting a whale. In general, these reactions have been stronger than anything observed from tagging in the most recent field seasons.

Mate noted that it is important to plan the force of ballistic delivery to achieve complete penetration and stop the tag from penetrating the animals beyond the planned depth. The use of "stops" to fulfill this need are appropriate.

Experience with attachment to captive animals has been excellent. Researchers have developed a dorsal fin saddle, made from heat-moldable plastics, which is attached to the dorsal fin with plastic pins. These pins have been designed to allow the entire saddle to break free, should the animal become entangled in net debris or strike soundly against the bottom of another animal. Inert plastic pins are used to attach the dorsal fin saddle; these are believed to be far superior to metal bolts that may have galvanic properties and irritate tissue. Having tracked a pilot whale for 95 days over at least 5,000 mi, Mate *et al.* are convinced that the package sizes and attachments are not debilitating. It is believed that past mutilation of dorsal fins has been due, in part, to the use of small and few attachments, allowing the hydrodynamic drag on the tag to produce pressure necrosis on the small surface area of the attachments. Adopting the opposite approach, at least five pins (at least 6 mm in diameter) are used in order to achieve sufficient surface area with the attachment to offset this drag. The use of a saddle further distributes the pressure across the leading edge of the dorsal fin and prevents the saddle from rotating. The inside of the saddle is padded with a closed-cell neoprene foam that provide channels for water to move about. The padding prevents abrasion and the channels prevent the possibility of overheating. Holes in the dorsal fin are made by a coring device rather than an auguring-type drill and investigators attempt, to the extent possible, to predict the circulation pattern and avoid the blood supply. Investigators need to be prepared either for cauterization or vasoconstriction techniques to control this potential problem.

In July 1990, Mate and Randy Wells tagged a bottlenose dolphin in Tampa Bay. The animal was tracked for 26 days before it lost the dorsal fin saddle. Observations made shortly after loss of the tag revealed that there were no visible holes in the dorsal fin, nor any "mutilation" or signs of infection. The areas where the pins had been inserted regained their pigmentation and were observed up to 16 months after tag loss and still appeared to be completely normal.

The question of attachment materials and longevity is one that warrants additional attention, including captive studies. The opportunities to conduct additional materials experiments like those of Geraci *et al.* (1985) are worthwhile. It is not clear whether captive circumstances will reflect open-water conditions or whether captive animals will behave differently than animals in the open ocean. If so, this would bias the effect of such experiments.

William Medway noted that one of the many problems with implants used for marking and tagging cetaceans is their unpredictable longevity (*i.e.*, retention). As a result, Geraci and Smith (1990) designed an experiment in which they surgically implanted various materials into the leading edge of the dorsal fin of bottlenose dolphins and into the dorsal ridge of beluga whales.

Three types of materials were implanted: metal rods (copper, *Copel, Inconel 671, Monel 400, 416* stainless steel and titanium), plastic rods (*HDPE-120, HDPE-250, Proplast I, Proplast II, Urethane, Aquaplast, and Polyform*), and metal rods coated with a plastic material (*HDPE-70, HDPE-120, Proplast I, Proplast I/Isotropic Carbon, Proplast I/Tecoflex, Dacron, Gore-Tex, Isotropic Carbon or Tecoflex*). Not all the materials listed above were implanted into both species. For details of the materials listed, the reader is referred to the publication by Geraci *et al.* 1985.

The response of the tissue to the implants varied considerably. The metal rods were expelled in less than three weeks by the bottlenose dolphins and in less than ten days by the beluga whales. The tissue response to the implants was intense. The histological description of the reaction is included in Geraci and Smith (1990). The longest retention, even though not ideal, was by the beluga whales for up to 58 days, while the *HDPE-120* implant into a dolphin was retained for 84 days before being removed surgically. The coated rods that were implanted only into the beluga whales were retained for 10 to 35 days before being extruded or surgically removed.

In conclusion, one material, high density polyethylene (HDPE), was retained in a dolphin for 12 weeks. One of the porous composites (*Protoplast I*) was retained for 8 weeks. When these materials were coated onto metal rods, they were all rejected within 3 to 35 days. All other materials were rejected within 3 to 35 days as well. All metals were rejected in less than 21 days by both species. Some of the materials tested have promise, especially the high-density porous plastics. Unfortunately, the galvanic properties of the metals were not considered and no doubt contributes to the rapid rejection.

Overview of Data Compression and Transmission

Presented by

Bernie McConnell, Paul Howey and Stan Tomkiewicz

Telemetry techniques on marine mammals are frequently limited by the rate at which data are relayed to the researcher. Effective data rates can be maximized by careful choice of data collection and transmission strategies. The following notes summarize some of those factors that should be considered in order to optimize data transfer and transmitter longevity.

If little is known about the animal's behavior, researchers should consider minimal on-board data processing and instead opt for transmission of raw data. Previous studies may provide sufficient information for the data to be collected and processed based on an *a priori* model with known parameter ranges. The activity of, say, pinnipeds may be divided into dive, surface and haulout phases, with data logged and transmitted appropriately.

The number of bits required to relay a parameter depends upon the parameter's possible range and the acceptable resolution. The resolution may be constant (*e.g.*, +/-10m depth) or a function of the measurement value (*e.g.*, +/-10% of value given). The latter type of error is achieved with a logarithmic transformation of the data, either in hardware or software.

Frequently interrogating sensors reduces battery life. However, infrequent interrogation results in greater error in timings (*i.e.*, dive duration). Some types of sensors whose information requires immediate action, *e.g.*, a submergence sensor that controls transmission start, may best be dealt with on an interrupt basis. The time resolution required when relaying depth profiles within a dive may either be fixed (for example, a depth value every 10 sec or some multiple of the sampling frequency) or may be a function of dive duration (for example, a depth value every one-fifth of the dive duration).

It is unlikely that the management question being asked requires every single dive record to be relayed. Transmitting every dive record through the Argos system is inefficient due to the satellites' sun-synchronous orbits and the lack of confirmation at the transmitter that a data set has been successfully received. The transmission of a sample of dive records introduces the problem of sampling bias. For example, a transmission strategy that relays data about only the last dive might bias towards those dives with prolonged subsequent surface intervals. To check for any such bias, dive parameters summarized over, say, the past six hours may also be transmitted. Data from a southern elephant seal transmitted via the Argos system allowed dive records to be reconstructed for 65% of its time at sea. A comparison of statistics from individual dive records and from relevant summary periods indicated that bias was insignificant. The variability in dive duration and shape in this data set indicated the importance of relaying individual dive records. By examining the numbers of repetitions of the reception of individual dive records, the dive record transmission strategy can be altered accordingly in the next deployment.

During transmission data will be subject to errors. To overcome this data may be retransmitted several times. A more efficient method is to incorporate a check-sum which, upon reception, will show if the data stream has become corrupted. Some techniques allow limited correction of errors. The data error rate may vary regionally. The Sea Mammal Research Unit has analyzed the results from 256-bit data strings transmitted from southern elephant seals in the Southern Ocean and grey seals in the North Sea. Errors occurred in 50% of North Sea transmissions, but in only 10% of Southern Ocean transmissions. This may be due to the higher background radio interference in the North Sea.

For HF and VHF tags, the transmission protocol can be defined by the worker. Longer transmission at higher data rates than used by Argos can be used. Various modulation techniques are also available, from simple pulse position coded systems to complex phase-modulated PCM techniques. Use of data compression and check-sums in the data are recommended.

The transmission of very high speed data (Mbits/second) along bare fiber optic links (resembling 20-lb monofilament fishing line), simultaneously to and from remotely piloted vehicles and missiles has been demonstrated over the past few years. Ranges of up to 50 km have been demonstrated. The use of this technique to retrieve data from and control a remotely attached tag should be investigated. Short-term monitoring of complex physiological parameters where sensors might produce complex data would seem ideally suited to the data rates available from use of this technique.

The quality and quantity of location fixes required should be defined *a priori*. This will be influenced, in part, by the resolution of the environmental data that will be used to interpret behavior. Post processing with Kalman filters or other algorithms allow some rejection of spurious locations.

Location Systems

The Argos positioning and data collection system became operational in 1978, with the "protoflight" of a TIROS-N satellite. This system was originally designed to recover environmental data from drifting buoys and balloons, aiding oceanographers and climatologists in their environmental studies. However, biologists soon recognized the system's potential use in tracking various species of mammals, particularly marine mammals. Those involved in the design of instrumentation began development of PTTs (platform transmitter terminals), transmitters specifically designed to recover data and to position buoys and marine mammals using the Argos system.

The Argos system is composed of three major segments. First is the space segment, which is composed of two polar orbiting satellites. The altitude of the satellites is approximately 830 to 870 km, the inclination is 98.7, and the orbital planes are mutually offset by 90 degrees. The periods are approximately 101 minutes, and the number of revolutions per day is approximately 14 per satellite. There are more satellite overpasses, thus more coverage, at the poles as would be expected from polar orbiting satellites.

The second segment of the Argos system is ground station command, control and processing. This segment provides processing and distribution of positioning information, as well as the distribution of data uplinked by PTTs. To establish position, a Doppler shift technique is used, employing the time of arrival of a message at the satellite, in addition to measurement of the frequency of the PTT transmission. Motion of the satellite and multiple uplinks are required to obtain positioning information. Data, however, can be collected from a single uplink. Argos maintains downlink sites at Wallops Island, Virginia; Lannion, France; and Fairbanks, Alaska.

The third segment of the Argos system is the PTT, which is the transmitter to be deployed on marine mammals. Typical output of a PTTs is 1.0 watt. However, for marine mammal applications, specialized PTTs have been developed utilizing lower power transmissions. Development of saltwater switch technology has synchronized the transmission uplink with the animals' surfacing. Highly sophisticated, microprocessor-driven PTTs have the capability both to log data and control the transmissions. A principal limitation of this system is its inability to transfer more than 32 bytes of data at the 400-bit per second uplink message data rate. The uplink frequency is 401.650 MHz.

There are several important points that are based directly on experience in the use of the Argos system. First, the average position accuracy for most wildlife PTTs has historically been on the order of 500 m to 1 km. The reduced accuracy as compared to drifting buoys is due to the fact that there are no transmissions while the animals are beneath the surface of the water, thus fewer uplinked messages. It is also possible for an occasional position to be off as far as 20 km.

Argos is the only satellite system currently available that, in an unaided manner, can directly position marine mammals at sea. Other systems that relay positions obtained from LORAN or GPS have been designed but are presently not coupled with more sophisticated sensor technology available for deployment on marine mammals.

Low earth-orbiting (LEO) satellite technology is currently being addressed at the World Administrative Radio Conference (WARC). Over the next 5 to 15 years, as frequencies are allocated for other LEO systems, alternatives to Argos may come into existence. Most of these systems were not conceived for use on animals. However, it is possible that these systems may be adapted to recover data and positioning information for the use of the scientific community.

The transmission protocol defined by the Argos system limits the amount of data that can be transmitted to a maximum of 5.7 bits/second (maximum 256-bit message at minimum 45-second interval). When the satellite availability is taken into account, along with the surfacing behavior of the animal, this rate is reduced manyfold. To successfully transfer complex sensor data *via* Argos to the user, various data compression techniques, with preprocessing onboard the tag, need to be utilized. With long Argos messages (256 bits), experience has shown that it is wise to include check-sums in each transmission.

The global positioning system (GPS) was developed as the result of a 1973 directive of the Deputy Secretary of Defense Department to provide for a joint program office to develop, test and acquire a space-borne positioning system. Out of a proposed 24 satellites comprising its total constellation, GPS (NAVSTAR [Navigation System Utilizing Time and Ranging]) presently has 16 satellites in orbit. Of the proposed 24 satellites, three will act as backup satellites. Because the constellation is not yet complete, there are occasional gaps in the 24-hr coverage for most locations.

GPS utilizes a time-of-arrival system, enabling a subject's receiver to obtain its position by computing the time of arrival of signals from the constellation of spacecraft in view. Two-dimensional and three-dimensional positioning are available.

Accuracy for single point positioning was originally designed to be 100 m; typically, however, performance is approximately 20 to 30 m. Two levels of accuracy are currently supported: one for military applications (P-CODE), another for commercial applications (CA-CODE). To assure the higher accuracy for military units, the spacecraft clocks are jittered in a predetermined fashion, thus causing an error in the commercial units. At the same time, the coded information is utilized to remove the effects of the clock jitter. The coded information is transmitted to military units on a special frequency and is encoded. "Differential GPS" is the technique utilized for commercial users to get around this limitation. In this case, an additional unit in a known location is used to correct the clock jitter effects introduced into the system.

The principal question associated with implementation of GPS for marine mammal research involves the utilization of ephemeris data transmitted by each specific satellite to describe its precise orbitography. Presently, the ephemeris information is typically considered "good" for a period of four to six hours by the GPS receiver. After this period of time, there is a degradation in the position resulting from the lack of an update from the use of an aged ephemeris data base. Several manufacturers limit the available positions from this aged ephemeris data base. Since each satellite downlinks its own ephemeris information in block as part of its downlink message, the receiver must be available to receive the entire ephemeris segment all at one time. This requires continuous time (30 to 50 sec) at the surface in the case of a marine mammal. The ephemeris information from each satellite must be recovered by the marine mammal once every four to six hours to continue to utilize the satellite to provide positions in most GPS receiving systems.

In contrast to this example above, early experimentation indicates that the ephemeris undergoes a graceful degradation over a period of two weeks, resulting in positioning inaccuracies of approximately 400 m by the end of the time period. However, it appears that some manufacturers are effectively limiting the use of this aged ephemeris by their GPS receivers. Also, the effect of aged ephemeris on the 1-sec position update rate for GPS units is not presently clear. The acquisition of ephemeris must also be viewed in relationship to the fact that the constellation of satellites (each with its own ephemeris) available to the receiver is constantly changing. As new satellites come into view, the downlink from those satellites has not been available for some number of hours. The ephemeris in the GPS receiver may be quite old and may be unusable in the positioning process of some receivers. It may take a special arrangement on the part of the user community to work with GPS manufacturers to make available PTTs with positioning capabilities more suited to marine mammal applications, particularly cetaceans. Pinnipeds, because of their haulout times, may be more suitable subjects, at least initially, for utilization of GPS.

Once position is established by the GPS receiver, there are many uses for the position information. It may simply be stored onboard for later physical recovery, it may be relayed directly through a transmission format such as FM or PSK, or it may be linked through the Argos or other proposed LEO satellite systems.

Active research is continuing to examine ways to utilize GPS in applications on wildlife and an emphasis has been placed on addressing the specific problems associated with the implementation of GPS for marine mammals.

III. REPORTS OF THE WORKING GROUPS

Working Group on Tag Delivery, Attachment, and Release Systems

TERMS OF REFERENCE

1. What are the ideal and minimum acceptable standards with respect to attachment position (*e.g.*, top of the head, mid-line, in front of, or behind the dorsal fin), longevity (days, weeks, months, years), and methodology (completely implantable, surface attachment, remotely attachable), by species or species group, as appropriate?
2. What is the present *proven* capability with respect to the maximum, minimum, mean, median, and modal number of days that various transmitters have remained attached and functioning, by species or species group, as appropriate?
3. What are or appear to be the principal impediments to development of a satisfactory attachment system or systems (*e.g.*, tissue trauma, infection, rejection reactions, external antenna), by species of species group, as appropriate?
4. How might the apparent problem or problems be overcome?
5. What are the critical uncertainties? What research would be required to resolve the uncertainties? How long would it take, how much would it cost, and what if any special facilities or equipment would be required to do the identified research?
6. What is the rationale and evidence for concluding that existing attachment methodology, possible alternatives, and/or recommended experimentation will not kill or injure animals, cause more than temporary (transient) pain or trauma, or affect animals in ways that will bias the study results? (Note: permits will be required to do anything that might kill, injure, or harm a marine mammal; permits cannot be issued for activities that involve "undue" pain or suffering or that are "unnecessarily" duplicative; and if the activities involve species listed as endangered or threatened under the Endangered Species Act, the potential benefits of the research must be greater than the potential risks, with respect to the protection and recovery of the species. Note also that the burden is on the researcher to provide evidence that the proposed research is *bona fide*, humane, not unnecessarily duplicative and, in cases in-

volving listed species, likely to be beneficial.)

The working group focused on the problem of instrumenting cetaceans. While problems remain in the attachment of instruments to pinnipeds, these were considered relatively minor compared to attachment methods for cetaceans. The group agreed to a number of recommendations, presented here in summary form. The discussions leading to these recommendations are reviewed in the section following the summary.

RECOMMENDATIONS

1. Systematic research on the basic behavioral and physiological effects of attaching instruments to captive and wild cetaceans should be funded and facilitated by a consortium of government agencies. This study is needed because future research could be regulated on the basis of potential harm that might result from use of such tagging methods.
2. Harnesses should not be used to attach instruments to cetaceans as they are difficult to fit and have been shown to increase drag, respiration rates and blood lactate levels in swimming bottlenose dolphins.
3. Presently available epoxies and adhesives should not be used on cetaceans, except possible on barnacles, which some species carry; research on new adhesives should not be inhibited, however.
4. Suction cup attachments are recommended for short-term deployments (1 to 4 days) on smooth-skinned cetaceans, and should have built-in release devices. It is recognized that the cups may migrate and pressure necrosis may occur on the skin of some species.
5. Instruments should not be deployed by mounts on the caudal peduncle, except for manatees, as they cause excessive drag and abrasion due to fluke movement.
6. Mounts that include bolting through some dorsal structure, such as a fin or ridge, should be used for deployments intended to last more than one month. This appears to be the best method of attaching instruments when animals can be captured. Holes should be cut using a coring device that removes tissue. Circulatory "hot spots" should be avoided. These can be located by using infrared thermography of the area or probing with a hypodermic needle prior to coring. Bolts made of Delrin or similar plastics should be used instead of metal and should be held on by steel or magnesium nuts isolated from the skin. Threaded ends of the rods should not touch the tissue. Multiple-bolt mounts should be used in place of mounts using two bolts.
7. If used, dorsal fin saddles should be made of PCS, *Teflon*, or other materials resistent to biological fouling. The saddle may be heat-formed for custom shape, and fitted to the fin or ridge with neoprene or open cell foam to reduce chafing. Tightness is critical, as tight saddles may cause pressure necrosis, while loose saddles may cause tissue damage at the attachment holes.
8. For instrument attachment on large cetaceans that cannot be captured, subdermal attachments should be delivered by shotgun or crossbow. This procedure requires extensive training and experience to ensure accurate placement. Crossbows have a greater margin of safety due to their lower velocities.
9. The smallest possible instruments, bearing the name and address of the owner, should be deployed with any given attachment method.
10. Research should be conducted into the question of which is preferable: attachments into muscle or into blubber.
11. Single attachment sites should be used whenever possible. When needed (*i.e.*, for heart rate monitoring), multiple attachments should be placed in line to reduce drag; measurement of the drag should be made.
12. A research program is needed to address attachment methods, the hydrodynamic drag and energetic costs of various package shapes and sizes, materials for both the internal (implanted) and external components of tagging systems, tissue and animal responses to various attachment techniques, and longevity of these same techniques. In a first phase of this program, captive animals housed in natural sea water, such as at the Naval Ocean Systems Center, should be used. A second phase should use animals in resident populations (both small and large cetaceans) to test attachment longevity. Concerned government agencies should cooperate to maintain a long-term testing program and database.
13. Researchers should collect and store tissue samples obtained during cetacean handling (*e.g.*, coring for dorsal mounts). A list of tissue banks and other laboratories interested in marine mammal tissues should be compiled, and these groups should be notified when tissue becomes available.
14. Repositories for works describing **successful and unsuccessful** attempts to capture and attach instruments to marine mammals should be established at the National Marine Mammal Laboratory in Seattle and at the Marine

Mammal Commission in Washington, D.C. These should function as lending libraries.

15. The editors of *Marine Mammal Science* should be formally asked to accept and publish papers on capture and attachment techniques.
16. To facilitate the permit process, the applicant should supply the following information:
    (a) demonstrated past experience with capturing and tagging marine mammals,
    (b) evidence of thorough knowledge of the tagging system to be used, and
    (c) demonstrated experience with the particular tagging system to be covered by the permit, or consultation with those who are experienced.
17. The suggested criteria listed herein should be used by applicants for research permits and the NMFS permit office to help judge the merit of research permit applications. The worthiness of permit applications should continue to be judged by peer review, preferably by experienced wildlife researchers.
18. Researchers wishing to gain experience with a particular attachment system or species should learn from others already active in the field.
19. Veterinarians are valuable as consultants during capture and tagging operations; however, their involvement should not be considered mandatory for tagging operations that do not involve capture.

WORKING GROUP DISCUSSIONS

Constraints on the Field of Cetacean Tagging

The working group noted that a critical need exists for information about many cetacean species, and that much of this information can only be obtained by attaching instruments to them. However, the attachment of such instruments to endangered species is often precluded because of their endangered status, even though much of the money available for cetacean research comes for work on these very species.

The group **recommends** that research be conducted to determine:

(1) the behavioral and physiological responses of animals to instrument attachment,
(2) the extent to which such attachment is physically or energetically harmful (see Testing), and
(3) whether future research will be regulated on the basis of potential harm that may occur as a result of tagging methods.

Types of Attachments

Harness. The group **recommends** that harnesses **not** be used to attach instruments to cetaceans. They have been used on beluga, gray and killer whales, and bottlenose dolphins. Harnesses were shown to be difficult to fit and often increased drag. Poorly fitting harnesses increased respiration rate and blood lactate level in bottlenose dolphins.

Adhesives. The group **cannot recommend** that presently available epoxies and other adhesives be used on cetaceans, except possibly on barnacles which some species carry. Some present adhesives cause dermal lesions; there is no evidence that any of them are useful. However, this should not inhibit research into the use of new adhesives.

Suction cups. The group **recommends** suction cup attachment for short-term instrument deployments (1-4 days) on smooth-skinned cetaceans. Suction cups have been used with success on bottlenose dolphins in a variety of settings, as well as humpback, gray, killer, minke, and fin whales. The drawbacks to this form of instrument attachment are that the cups may migrate and pressure necrosis may occur on the skin of some species. The group further **recommends** that if suction cups are used they should have built-in release devices when deployed on species that retain these mounts for long periods.

Surgical implants. The group **makes no recommendation** concerning deployment of instruments by surgically implanting them. Surgery can be of use in limited situations, including captive cetaceans where appropriate surgical procedures (specified by some animal research committee guidelines) can be followed. Surgical implant limits the transmission distances of RF instruments to 1 m or less, which further restricts the usefulness of this approach.

Caudal peduncle mounts. Except for manatees, the group **recommends against** deploying instruments by means of mounts on the caudal peduncle. Where such mounts have been used on cetaceans (by W. Evans, C. Juraz, and J. Cousteau) they have caused much drag and abrasion due to the motion of the flukes. Fluke damage from other causes is common in larger whales.

Ingested instruments. The group **makes no recommendations** concerning deployments of instruments in cetacean stomachs. The group notes that within reasonable size limits these are probably not harmful; foreign objects are common in cetacean stomachs. However, the problem of retrieving ingested instruments remains unsolved. The method will probably be most useful on captives where instruments can be queried for data over short distances, as in surgical implants. This technique has been tried by S. McKay.

Dorsal mounts. The group **recommends** using mounts that include bolting through some dorsal structure, such as a fin or ridge, whenever deployments are intended to last more than one month. This seems the best method of attaching instruments when the animal can be captured.

1) ***Methods***: The group **recommends** that holes be cut through the fin or ridge using a coring device that removes tissue (see Testing for further considerations). The group **recommends** bolts made of Delrin or similar plastics rather than metals (some testing of materials is needed — see Testing), and that bolts be held on by steel or magnesium nuts that are isolated from the skin. The group **recommends** that bolts be threaded only on their ends, not where the bolt touches cored tissue. Based on techniques developed to date the group **recommends** multiple bolt (3-5) mounts be used instead of mounts having only two bolts. Avoidance of circulatory "hot spots" during mounting is possible by infrared thermography of the area, or by probing with a hypodermic needle prior to coring. The group **recommends** that if saddles are used they be made of PVC, *Teflon* or other materials that resist biological fouling. Saddles may be heat-formed to custom shape each mount for the best fit. Saddles should be fitted to the fin or ridge with neoprene or open cell foam to reduce chafing. Saddle tightness is of critical importance. Mounts that are too tight may cause pressure necrosis, while those that are too loose may cause tissue damage at the attachment holes.
2) ***Longevity***: The group **reached no consensus** on whether saddle mounts should be left in place after the instruments have been removed. On some species and in some environments biological fouling, entanglement in fishing gear, wicking of bacteria into the wound sites and animal attempts to dislodge the saddle may argue against leaving them in place. These may not be important for other species in other environments. Research into these and other results of dorsal mounts must be conducted before a recommendation on saddle removal can be made. If this research (see Testing) reveals that such mounts inevitably cause damage then appropriate release mechanisms should be built into them.

Ballistic Mounts. The group **recommends** that subdermal attachments delivered by shotgun or crossbow be used to attach instruments to large cetaceans for which capture is not an option. Shotgun delivery methods should be used with extreme caution and only after extensive training and experience with accurate placement. Crossbow delivery systems may have a greater margin of safety due to the lower velocities.

1) ***Methods***: Two systems, those developed by W. Watkins and by J. Goodyear, were discussed in detail. The anchor (barnacle) mounts presently being used by B. Mate were not discussed.
   The Watkins system involves a rigid, tubular dart which is fired from a specially modified shotgun into the blubber at angles of 30° or less, usually from behind the animal. Depth of penetration is regulated by a stop. This was considered a critical feature to prevent excessive penetration. All instrumentation is included inside the shaft of the dart. PTT circuitry is presently being configured for this system. J. Goodyear has developed two ballistic systems. In one, a dart head and encapsulated VHF circuitry imbed in the blubber leaving only the antenna protruding through the skin. In the second, only the dart head penetrates the skin and blubber. The instrument is kept external by means of a transdermal, jointed swivel that allows the instrument to align parallel to the swimming animal and current flow. The penetration angle and depth can be regulated 30° to 90° and 5 to 9 cm, respectively.
2) ***Longevity***: The longest that the Watkins system (RF tag) was known to have remained attached was six weeks (the length of the cruise). The Goodyear VHF capsule tag has stayed in a whale for up to 4 years. The maximum longevity of these tags is unknown because either the instruments they contained stopped transmitting, the animal migrated, the animal was killed during a subsistence harvest, or a combination of the above. Decoupling these two variables should be an important goal of a

testing program (see Testing). The group concluded that both the Watkins and Goodyear systems had advantages, and **did not recommend** one over the other. The Watkins system is internal, which reduces disturbance to the animal caused by movement of the instruments on the skin. The Goodyear system can be coupled with many kinds of instruments, not just radio frequency beacons and acoustic transponders, as in the present Watkins system. The group **recommends** that with any attachment system users deploy the smallest instruments possible.

3) ***Attachment into blubber or muscle***: The group **recommends** that research be conducted into the question of whether attachments into muscle or blubber are preferable. Wound sites in blubber rapidly liquify and release the dart, especially if a large transdermal opening is left. The veterinarians present stated that objects imbedded in muscle may be more readily encapsulate than in blubber, and if so such mounts might be less readily rejected than attachments into blubber. However, rigid attachments that cross the fascia between blubber and muscle may degenerate because of movement along this interface.

4) ***Responses to tagging***: Animals respond to the ballistic delivery system in a variety of ways, from showing no measurable response to showing a slight startle response. Animals show a greater response to chasing prior to tagging than to tag application alone. The factors that determine how a cetacean will respond during tagging include the a) finesse of the approach, b) cleanness of the shot (it should not ricochet or strike the water), c) gender of the animal (male humpback whales have been found to react to chasing more than females).

Multiple attachments. The group **recommends** using single attachment sites whenever possible, and placing multiple attachments, for example in monitoring heart rate, in line to reduce drag. Measurements of the drag created by multiple attachment sites are needed (see Testing).

Tag labeling. The group **recommends** that all instruments, irrespective of attachment or release method used, should be labeled with the owner's name and address with instructions for forwarding in the event of recovery.

Testing

The group recognized the importance of future research into the effects of instrument attachments to cetaceans. A program of systematic research into the basic principles and problems of attachment could fill this information gap and place future research on a more sound footing.

The group **recommends** that a research program address (a) attachment methods, (b) hydrodynamic drag and energetic cost of various package shapes and sizes, (c) materials for both the internal (implanted) and external components of tagging systems, (d) tissue responses to various attachment techniques, (e) longevity of these same techniques, and (f) animal responses (stress) to and healing rate following various attachment methods.

The group **recommends** that such a program begin with captive animals, but not in aquaria where high bacteria counts and other conditions are liable to confound results. Instead, it **recommends** that captives being housed in natural sea water, such as the bottlenose dolphins at the Naval Ocean Systems Center in Hawaii and San Diego, should be used. Trained animals in such situations could be used to make direct measurements of drag and energetic cost during exercise. The group **recommends** that if the NOSC animals become available for a testing program then concerned governmental agencies (*e.g.*, Navy, NMFS, and MMS) cooperate to maintain a long-term testing program and database that would inform and benefit the marine mammal community.

The group **recommends** that, in a second phase of testing, instruments be deployed on animals in resident populations (both small and large cetaceans) to test attachment longevity. By visually checking the progress of attachments for long periods, researchers can separate tag longevity from the problem of animal migration as noted above (see Longevity of Ballistic Tags). In the small cetaceans, such as bottlenose dolphins in Sarasota Bay, Florida, systematic recapture could be used to track whether tissue damage occurs. Humpback whales caught in fishing nets in Newfoundland, stranded pilot whales, and killer whales in Norway might be used in this testing. Other possible test opportunities are gray whales off Vancouver Island and minke whales in Puget Sound.

Biopsies

The group **recommends** that researchers collect and store tissue samples obtained during cetacean handling (*e.g.*, coring for dorsal mounts). Further, a list of tissue banks and other laboratories interested in marine mammal tissues should be compiled, and these groups should be notified that tissues from marine mammals often become available. DNA analysis and pollution studies based on these tissues could benefit the marine mammal community.

Release Mechanisms

The group considered separately the questions of releasing instruments attached to animals, and releasing the mount mechanisms by which they are held to the animal. The group agreed that the development of mechanisms to release instruments on command seems central to the future of instrument work on cetaceans and other marine vertebrates. The group **recommends** that research be conducted toward development of systems that use a remote signal to trigger instrument release (similar to that produced by Wildlink). Two different systems were discussed for floating released instruments so that their antennae remain upright.

The question of whether dorsal or ballistic mounts should be released from the animal cannot be answered until more is known about the longevity of various mount techniques. Dorsal mounts could be removed by spring-loading the bolts and securing them with magnesium (corrodible) cotter pins. Ballistic mounts could be removed by making the dart toggles out of biosoluble materials, such as that used in surgical staples. However, this may prove unnecessary given the natural liquefaction that occurs around dart sites.

Concerns

The group discussed several issues of concern to all practitioners in the field of instrument attachment on marine mammals, regardless of the system used or species studied. These were:

Documentation. The group noted that one reason that animal capture and instrument attachment continue to be discussed is that past successes and failures have either not been documented in print, or have been documented in the "gray literature." The group noted that to successfully plan research, defend permit applications, and educate newcomers in the field each field project should systematically document its methods. The group **recommends** that repositories be established in the libraries of the National Marine Mammal Laboratory in Seattle, Washington, and the Marine Mammal Commission in Washington, D.C., specific to capture and attachment techniques, and that researchers send existing materials to these repositories. The group further **recommends** that the editors of *Marine Mammal Science* be encouraged by letter to accept papers on techniques and their success/failure rates for the benefit of the entire community.

Permits. The group noted that difficulties in obtaining research permits often stem from the NMFS permit office having unclear criteria from which to judge and defend applications. Conversely, applicants often prolong the permit process by failing to properly document their knowledge and experience. To facilitate the permit process, the group **recommends** that the applicant supply the following information with the application: a) demonstrated past experience with capturing and tagging marine mammals, b) evidence of thorough knowledge of the tagging system to be used (based on the literature referred to under Documentation), and c) demonstrated experience with the particular tagging system to be covered by the permit, or consultation with those who are experienced.

Education. The group **recommends** that those wishing to gain experience with a particular attachment system or species learn from others already active in the field. The group concluded that no centralized certification system was feasible, desirable, or necessary. The peer review system in the present permit process is adequate for rejecting unqualified applicants.

Veterinary Concerns

The group, which included two veterinarians, **recommends** that the presence of veterinary staff or other qualified specialists at captures and instrument deployments should be considered desirable but optional. They should not be considered mandatory participants, and should not be stipulated as a condition of the permit process. It was noted that veterinarians are usually no more successful at preventing death during captures than are researchers trained in other fields. Furthermore, the antiseptic techniques used during instrument attachment are not specific to veterinary staff; antisepsis is promoted by common sense and cleanliness in most cases. The special role played by veterinarians in capture situations is that of experts in handling unusual and unexpected situations, such as discovering and assessing pathological conditions.

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Working Group on Instrumentation

TERMS OF REFERENCE

1. What are the basic user interests and requirements with respect to (a) location data and (b) corollary environmental and physiologic data, by species and species group, as appropriate.
2. Given the identified user interest and requirements, what are the basic instrument requirements with respect to such things as size, power output, longevity, sensors, frequency and accuracy of data transmissions, pressure housings, temperature stability, etc., by species and species group, as appropriate.
3. Which of the identified instrument requirements can and cannot be met with existing technology?
4. What problems must be overcome to meet the identified user requirements, by species and species group, as appropriate?
5. What, if any, of the identified problems are unlikely to be overcome, at least in the foreseeable future, and thus should be viewed as constraints (*e.g.*, substantial reduction in power requirements or size of power supplies)?
6. What research, development, testing, *etc.*, would be required to overcome the presumably "resolvable" problems? How long would it take, how much would it cost, and what special logistics or other arrangements would be required to accomplish the identified tasks?

The deliberations of the working group on instrumentation resulted in the following recommendations. The discussions leading to the individual recommendations are reviewed in the section following this summary list.

RECOMMENDATIONS

1. To address present power limitations, a feasibility study should be undertaken to investigate a potential source from a package attached to a diving animal. This should include determining: (1) how much energy could be obtained from the pressure differences between surface and depth on an individual dive; (2) how this energy could be converted to electrical energy; (3) how this energy could be stored until sufficient to power a transmission; and (4) how frequently these transmissions could be sent from, for example, an Argos satellite tag.
2. The basic tag should always have the user interaction based on menu choices. When small enough microprocessors capable of addressing 640 K become available, the advanced tag should use programming in a higher-level language (*i.e.*, C++) to allow greater researcher flexibility and, when LEO satellites are available, to allow reprogramming of units already deployed.
3. Researchers should work with Service Argos to develop ways to describe the distribution and causes of errors associated with each location type. Argos should

be encouraged to provide more information on their subclassification decision algorithms.

4. Discussions should take place with GPS designers to determine if it is possible to arrive at a location device that meets the space and power requirements of most marine mammal researchers.
5. The most promising future swim velocity meters will use acoustic transducers at each end of the package to compare forward and backward doppler shifts. The long-term goal is to measure animal velocity with reference to unmoving water a few tens of centimeters from the animal's surface.
6. Efforts should be made to maintain the animals that are presently scheduled to be moved from the Naval Ocean Systems Center's Hawaii Laboratory for benign testing of sensors. If this is impossible, other arrangements should be made to allow continued access to other animals for such testing and development. Oceanaria should be encouraged to recognize their responsibility for assisting in such testing as part of their stewardship of captive marine mammals.
7. Calibration data should be recorded along with data stream for future conversions into real values in the absence of having access to the original calibration curves.
8. The basic tag should include emersion, pressure and temperature sensors, which need little or no development.
9. The working group's ranked preference for biological data sensors is (in order): orientation (X,Y,Z), heart rate, velocity, feeding, acoustic, respiration, and conductivity; each with varying developmental times.
10. Radio frequency transmission capabilities should be developed for handling digital data at rates of tens of kilobytes per second for near-term use and at rates of hundreds of kilobytes per second for longer-term needs. Associated data processing techniques need to be developed to send data to the radio frequency transmitter in an order of priority that maximizes data return during any one transmitter exposure.
11. Devices should be developed for remotely releasing and retrieving externally mounted instruments.
12. Further investigation of the use of fiber optic cable for short-term, very high data transfer rates is needed. Issues such as deployment and detachment will need to be modified for use with marine mammals.

WORKING GROUP DISCUSSIONS

Basic and Advanced Tags

Tags discussed at this workshop have paraded under a variety of names. This group felt that the terms "basic tag" and "advanced tag" best identified the differences in our minds.

These two tags differ on a quantitative basis but not a qualitative one. Both contain three essential components: sensors, microprocessor and data storage, and transmitter. The basic tag contains three sensors: emergence, temperature and pressure. The transmitter unit is an Argos satellite transmitter. The advanced tag contains the same three sensors plus a variety of other sensors, it employs a more sophisticated microprocessor and has enhanced data storage, and it can use one or a combination of radio frequency, satellite or acoustic transmitters. Although it is recognized that communications to the satellite are also radio frequency communications, in this report radio frequency transmitters refer to those transmitting to ground or aircraft based receivers, not satellite receivers.

This report is organized around the three components of the tags: transmitters, microprocessors and data storage, and sensors.

Transmitters

When transmitting, the transmitter is usually the major power drain in all tag configurations. Although we may expect incremental improvements in battery capacity and improvements in power consumption of many tag components including marginally more efficient transmitters, these developments were not addressed in detail by the working group because these changes will be driven by users wielding much greater economic power than the marine mammal community.

Batteries: Some of the working group members have demonstrated that pressure housings are not necessary for batteries. This will allow for greater freedom in total package design because batteries do not need to be placed in pressure housings. Alkaline cells have been pressure tested to 10,000 psi and lithium cells to 1500 m when air spaces were filled with mineral oil.

One potential source of power that should be investigated is that associated with pressure differences experienced by any package attached to a diving marine mammal.

> **Recommendation:** A feasibility study should be undertaken to determine (1) how much energy could be obtained from the pressure differences between surface and depth on an individual dive; (2) how this energy could be converted to electrical energy; (3) how this energy could be stored until sufficient to power a transmission; and (4) how frequently these transmissions could be sent from, for example, an Argos satellite tag.

Antennas: Antennas represent an area in which significant improvements are unlikely. The present designs for RF and satellite antennas have been chosen because they are the most tolerant to detuning next to the animal and to antenna orientation. Improvements in antenna gain would come at the expense of antenna ruggedness and could result in critically-tuned, unforgiving antennas. This was not deemed to be a responsible trade-off. If other antenna designs are tested, they should be tested on packages that are attached to animals that can be physically handled rather than on remotely attached transmitters where there is little control over antenna orientation.

There was a recognition that the two-way communication capabilities that will become available with LEO satellites can have significant advantages in many situations. Because antenna requirements will be dictated by frequencies chosen, a process currently underway, the group could make no specific recommendation at this time other than emphasizing the need to adapt to the LEO technology as soon as possible. In addition to the two-way communication characteristics, data transfer rates will be orders of magnitude greater than currently available with Argos, but as yet are not completely defined.

Microprocessors and Data Storage

Current trends in microprocessors and memory will continue the path of smaller, more sophisticated, increased storage density, and reduced power drain. This is not a field we will influence; rather we should be aware of changes in the field and be prepared to incorporate new advances that address our needs.

The current quest for the smallest microprocessors have led to the use of 8-bit-bus units, primarily because of microprocessor size and limitations in the available space for making connections to the microprocessors. The maximum of 64 K of code in these microprocessors has made machine language programming mandatory. Within these constraints, it is better to provide the user with options for setting parameters rather than programming the microprocessor. For many circumstances a small increase in size can be tolerated until larger microprocessors with 640K of addressable space become available. These units, some of which are currently being used, can be programmed in higher languages such as C++.

> **Recommendation:** The basic tag should always have the user interaction based on menu choices. The advanced tag should make use of the ability to program in a higher-level language, *e.g.*, C++. Such an option would allow greater researcher flexibility and when LEO satellites are available would offer the ability to reprogram a unit already deployed on a marine mammal.

Sensors

Position: Argos gives nominal position accuracy of 1 km. Most users felt that they often can achieve better position accuracy than this, substantiated particularly for seals by tracking movements within defined estuarine channels or along known beaches. In addition the raw data can be improved by post analysis using species specific biological knowledge of the animal, *e.g.*, maximum swimming speed. It was suggested that further improvement in the use of Argos data could be obtained if Argos would provide more information about the ten subclassifications within class 0 data. Experience has shown that some of these subclassifications are better than others for tracking data but without more information on the parameters involved in assigning incoming data to these subclassifications, researchers are at a disadvantage in an attempt to optimize position data return.

> **Recommendation:** Researchers should work with Argos to develop ways in which Argos can describe the distribution of errors associated with each location type and their causes. Argos should be encouraged to provide more information on their subclassification decision algorithms.

The Global Positioning System (GPS) can provide typical position accuracies of within 20 m at temperate and tropical latitudes and within 50 m at high (>60°) latitudes. These accuracies can be increased if there is selective availability or through the use of differential GPS. The receiving unit requires a minimum of 50 sec (average 90 sec) on the surface periodically to acquire an update to its ephemeris data set which provides necessary information on the locations of the satellites. These data are broadcast every 50 sec so the uninterrupted surface time can be any time during the day. The system is capable of using past history to degrade gracefully over a couple weeks to within 400 m accuracy if it fails to obtain ephemeris data. It is currently unknown as to how often the ephemeris must be updated before the unit is incapable of fixing position and what effect this degraded ephemeris will have on the validity of a fix. Theoretically, ephemeris data never should be required but that is not the approach the manufacturers have taken.

Current units are dependent on extended (within the context of cetacean tracking) surface times with antenna exposed. Presently available units measure 7.5 by 10 cm and weigh 325 g. They draw 1.63 watts when the receiver is activated and less than a milliwatt when quiescent. Currently available batteries provide 21 hrs of continuous reception, which could translate into more than 5 months of usable life, if ephemeris data and position data could be acquired in as few as four daily surfacings of two minutes each. The temperature operating range of the GPS units is -40° to +80° C and thus they should function even on pinnipeds hauled out in the arctic.

The currently available GPS boards present serious problems for using this system with most cetaceans. Possibly there can be a GPS development reminiscent of the Argos development whereby the marine mammal community is willing to give up the ultimate sophistication of the system for the payback of reduced power requirements and size.

Recommendation: Discussions should take place with GPS designers to determine if it is possible to arrive at a location device based on GPS which meets the space and power requirements of most marine mammal researchers.

LORAN can provide improved position accuracy compared to Argos under the right subset of conditions. An example was presented concerning tracking loggerhead turtles in the environs of oil platforms. Position accuracy of 50 m is expected. The turtles will rebroadcast the LORAN signals received by a transmitter on the turtle. The rebroadcast frequency is at 900 MHz to a receiver at the top of an oil platform providing a tracking range of 16 km. All LORAN data reduction will be done at the central site. The turtle unit weighs about 900 g and is about 18 cm x 7.5 cm x 4 cm. It is powered by three lithium D-cells giving a life of about one year.

Emersion: Emersion sensors are necessary in both the RF tag and the satellite tag because both should transmit only when the animal is at the surface and the antenna exposed. Currently used sensors are: optical, conductivity, and differential conductivity. Sensing emersion by low power interrogation of antenna impedance is being investigated. The first three are known to have low power drain, particularly in combination with a microprocessor that uses duty cycling, switching, and other information such as pressure to dictate sampling of the emersion sensor. Information on the power drain of the fourth technique was not available to the working group. A fifth method suggested was natural resonance of the tag housing. This would change upon exposure. This is a possible area for future research because it requires sensing nothing external to the unit. This suggestion did not attain status of a recommendation because the current sensors are preforming adequately. It was noted that if a situation existed in the future in which a tag was fully implanted in an animal, the low power interrogation of the antenna impedance was the only technique discussed that could reliably detect emersion.

Environmental Sensors

Temperature: Temperature sensors are available with accuracies to 0.001° C and with drift of 0.002° C per month for oceanographic applications. The drift becomes much greater if the sensor is pressure cycled so the transducer must be placed in a pressure housing. In order to track animal movements across ocean front temperature gradients or through thermoclines, a time constant of 10 sec was deemed necessary. This time constant is achievable through miniaturization of the pressure housing of the temperature transducer. There are some engineering problems with providing sufficient thermal isolation between the small temperature transducer pressure housing and the larger tag to which it is attached. It was decided that these problems were manageable and no additional work on temperature sensors was recommended.

Pressure: There is an abundance of pressure sensors available and no development is needed in this area. Pressure sensors will drift but they are the easiest of all sensors to field calibrate because when the emersion sensor indicates surfacing, they can be recalibrated to zero. Fortunately it is the intercept of the calibration curve that shifts, not the shape of the curve itself. The transducer housing should be titanium to avoid the inevitable corrosion problems associated with stainless steel.

Conductivity: An inductance coil is probably the best measuring device. It is subject to slow baseline drift but even with drift would still be able to indicate marine mammal movement across interfaces between water masses of different salinities. In the near-term the inductance coil is the sensor of choice. For longer term, conductance could be measured by changes in refractive index using nonaligned transmitting and receiving fiber optics. This latter device could be expanded to include measures of chlorophyll in the water, *i.e.*, placing a miniature, limited spectrophotometer on a marine mammal is a possible long-term goal.

Behavioral Sensors

Orientation: In order to reconstruct the three-dimensional movements of marine mammals a flux compass appears the best current choice. The group discussed a reliable but unconfirmed report that an inexpensive three dimensional flux compass has been developed. This unit is reported to be about one cubic inch and draws low power. If such a unit is available, it could be incorporated into data loggers and larger transmitter packages quite quickly. A gyrocompass in a package about twice as large is commercially available. This unit includes a microprocessor and provides RS-232 data to a logger or transmitter. It is not a low power unit and hence is applicable only for specific, short-term studies.

Heart Rate: Three possible ways of measuring heart rate were discussed: (1) electrical, either via single point electrodes (implantable packages or surface-mounted packages) or via two electrodes (surface-mounted packages); (2) acoustic via an implanted hydrophone; and (3) acceleration experienced by an implanted package. In all cases signal filtering and possibly additional processing will be required to extract the signal from noise associated with animal movement. Additional data on all three methods need to be acquired before their relative values can be determined. The acoustic measure has the advantage that it is the method of choice for measuring respiration, as discussed later.

Velocity: Mechanical devices currently in use are proving to be quite satisfactory and less susceptible to fouling than initially anticipated. There is need to lower the stall speed of these devices. Velocity should be able to be measured from 10 cm/sec to 5 m/sec with an accuracy of 5%. Any device mounted on an animal will give readings somewhat contaminated by turbulence and boundary layer effects near the animal. Ideally the speed measure should take place off the surface of the animal. Acoustic devices being developed to look at speed relative to a packet of water tens of centimeters from the device are more the size of a seal than deployable on a marine mammal. However, the traditional trajectory of such research tools is that they become smaller and draw less power as development continues. It is hoped that such devices will eventually be suitable for use on marine mammals. Electromagnetic sensors are subject to fouling, *e.g.*, a fingerprint on the electrode can produce unreliable signals for a week. Lever arms and strain gauges or fiber optic wands that record velocity by bending might be applicable to some situations although concern was expressed for their robustness in the presence of animal-animal or animal-environment contact.

> **Recommendation:** Among future replacements of the currently reliable mechanical velocity devices, the most promising appears to be placing acoustic transducers at each end of the package to detect velocity by comparing forward and backward doppler shifts. The utility of such an approach should be investigated recognizing that the long-term goal is a measure of animal velocity referenced to a water mass a few tens of centimeters from the animal's surface.

Feeding: Linking data from an ingested temperature-modulated acoustic transmitter to an external data pack or transmitter is the most direct way to measure feeding success. Acoustic transmitters have been maintained successfully in seals' stomachs for up to a year and in one instance an acoustic transmitter was successfully fed to a free-ranging cetacean. Placement of an accelerometer on the head was considered to be method that would be appropriate for certain species of pinnipeds that consistently head-lunge for prey. Reed switches and other measures of jaw opening could also be appropriate for certain species.

Acoustic: In this case the sensor is much less of a problem than the data compression, storage and transmission. If the question of interest is animal vocalizations, the hydrophone can be mounted on the animal. If the question of interest is the acoustic environment of the animal, the hydrophone needs to be mounted 10 cm or more away from the animal to escape near-field turbulence and motion generated noises. It was recognized that the data problems could be greatly reduced if one has foreknowledge of the signal on which measurement is being attempted, *e.g.*, an approximately 60 Hz signal. For a number of short-term experiments the ability to return very broad-band data through an attached fiber optic cable should not be discounted.

Respiration: There was agreement, based more on intuition than data, that a hydrophone on an implanted tag would be the best way to measure respiration and that the signal to such an internal hydrophone would be quite unmistakable.

Physiological Sensors

Blood gases: There was little optimism for obtaining any meaningful measurements from any such sensors attached to a tag on a long-term basis. Specific instances for short-term, data pack use have been described in the literature.

Internal temperature: It was recognized that any temperature probe associated with an implanted transmitter would be measuring transmitter temperature unless effectively thermally isolated. Internal temperature of interest is in the muscle rather than in the blubber where an implantable tag would reside. A possible solution would be to implant a second temperature-modulated acoustic tag in the muscle mass which would relay data as described above for the feeding sensor. Sufficient scientific justification for such a double-tagging of an animal was not readily apparent.

Sensor Testing and Development

It was recognized that sensor development and testing would require access to captive marine mammals. Individuals have worked with various aquaria or government labs to conduct tests in the past. This type of access must be maintained.

Recommendation: Efforts should be made to maintain the animals scheduled to be moved from the NOSC Hawaii Laboratory. Either they should be kept at that facility or moved to another facility where they would be available for benign testing of sensors. If this is impossible, other arrangements should be made to allow continued access to other animals for such testing and development. Oceanaria should be encouraged to recognize their responsibility for assisting in such testing as part of their stewardship of captive marine mammals.

Sensor Calibration Data

Recommendation: Calibration data should be recorded along with the data stream so that in the future the stored data strings can be converted into real values long after the departure of the original investigator and his or her notebooks with the calibration curves.

Sensor Priorities

Recommendation: The basic tag should include emersion, pressure and temperature sensors. There is little or no development needed for these sensors.

Recommendation: The following sensors are ranked in order of preference for the biological data by the participants at the workshop: orientation, heart rate, velocity, feeding, acoustic, respiration and conductivity. Some of these have a shorter developmental path than others, as outlined above.

Experimental Designs

Six types of experimental designs of varying levels of data complexity were considered. The first is the basic tag providing Argos position information with limited pressure and temperature data transmission capacity.

The second is the advanced tag with sensors and data compression techniques such that the information is retrievable through multiple identification codes using Argos.

The third is the use of combined acoustic and radio frequency tags in conjunction with ship-based tracking of the animals and making concomitant behavioral observations. It was recognized that many significant biological and human-impact studies can only be accomplished through such close-up monitoring of marine mammals.

The fourth design is a further elaboration on the third one. Using reasonably available technology, data transfer rates from the RF tag would probably be limited to 9600 baud. The acoustic tag can transmit either digital or analog signals because there is not the requirement for data storage in anticipation of a surfacing. When the sensor suite on the animal is such that compressed data obtained during a dive exceeds the amount that can be transmitted at 9600 baud during a surfacing sequence, broader band RF transmission is required. Although such RF transmission is certainly routine, it has not previously been considered for packaging into an RF tag. Research needs to be directed toward such a tag (see recommendation below). Much of this research could also be applied to eventual LEO tags.

Two experimental designs, the third and fourth above, were allocated to studies involving close ship contact with tagged marine mammals because of the number of important biological questions that can only be answered in association with animal behavioral observations.

The fifth design is one in which the large amounts of multiple sensor data are collected on a data package that either can be recovered from the animal (in the case of some species of pinnipeds) or can be recovered from a remotely released data package. Research needs to be directed toward remote release of a data package (see recommendation below).

The sixth design is a specialized one in which several kilometers of fiber optic cable remain attached to a package generating data at very high rates (*e.g.*, acoustic and video). This would obviously be for a short term study but could be very valuable in specific situations.

Recommendation: Develop radio frequency transmission capabilities for handling digital data at rates of tens of kilobytes per second for near-term use and at rates of hundreds of kilobytes per second for future range needs. For both transmission data rates, appropriate data processing techniques need to be developed so that the data can be sent to the RF transmitter in an order of priority that will maximize data return during any one transmitter exposure.

Recommendation: Develop reliable methods of remotely triggering release of data packages and of retrieving the data packages.

Recommendation: Further investigate the use of fiber optic cable for short-term, very high data transfer rates. Issues such as deployment and detachment will need to be modified for use with marine mammals.

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Working Group on Data Transmission and Analysis

TERMS OF REFERENCE

1. What are the currently available systems for receiving and relaying telemetry data from radio-tagged and acoustically tagged cetaceans?
2. What are the shortcomings of the existing systems with respect to obtaining location and corollary data cheaply and effectively?
3. How might the shortcomings be overcome?
4. Which, if any, of the identified shortcomings are unlikely to be resolved within the foreseeable future and thus should be viewed as constraints?
5. What might usefully be done to overcome the identified shortcomings? How long would it take, how much would it cost, and what, if any, special logistics would be required to accomplish the identified tasks?

The task of this working group was to outline the limitations which confront cetacean researchers in answering management-related problems. The group excluded attachment techniques and minimized its discussions of technical matters related to tag construction, as these topics were to be covered in the other two working groups. The term 'datalogger' is used to mean any data gathering device, no matter how the data are stored or transmitted.

This working group report provides a summary of the discussions that culminated in the following recommendations, aimed at overcoming present limitations:

SUMMARY OF RECOMMENDATIONS

1. Convene a working group to examine current data logger techniques and resulting behavior datasets, to assess the applicability of these techniques to all marine mammals, and to formalize definitions of parameters for inter-study comparison. Promote interaction between and within groups analyzing data and groups developing data logger technology.
2. Develop a basic tag that is essentially a data logger which is modular yet flexibly configured. This tag should provide location, dive, and temperature data, with a peripheral device that provides high accuracy location data. Data retrieval options should be considered.
3. Develop an advanced tag that elaborates on the information obtained by the basic tag, using specialized sensors that focus on special aspects of diving such as foraging and/or measurement of physiological variables.
4. Integrate marine mammal behavior with oceanic data such as bathymetry, climate, current, acoustic profiles, primary productivity, fisheries, *etc.*, and other aspects of the species. Compile a list of appropriate data sets, with their availability and format, and study what software/hardware is available and most appropriate for displaying and cross-correlating behavior data with oceanic datasets.
5. Researchers should work with Service Argos to develop ways to describe the distribution and causes of errors associated with each location type. Develop filtering algorithms should be developed that will aid in the interpretation of location fixes (especially class 0 locations) with variable and/or unknown confidence limits.

Defining Behavior Parameters and Review of Datalogger Technology

The working group recognized that behaviors are being interpreted differently by various investigators, which makes correlations between discrete areas and among individual researchers difficult. It was decided that there was a need to develop definitions for behaviors and other parameters collected by tags to maintain consistency between laboratories.

There was discussion on the minimum data parameters which must be measured to answer management and research questions. The datalogger techniques often dictate some of these parameters, and must be taken into consideration in this exercise. There was much discussion on the analytical methodology which has been, or could be, used on the collected data. Likewise the concerns with archival of the massive volumes of data being collected were also discussed.

As a result of these discussions, the working group felt strongly that there was a need to convene a workshop to address these concerns, and that such a workshop should be held as soon as possible, as the field of tagging and tracking is developing at a rapid rate.

There was also much discussion on the need for interactions between the datalogger developers and the researchers analyzing the resultant data to ensure that the parameters that the dataloggers are designed to record are, in fact, the parameters of most use in the required analyses.

Recommendation: Convene a workshop to examine current datalogger techniques and the resulting behavior datasets. The objective is to assess the applicability of these techniques to other marine mammals. This will enable the formal definition of parameters (*i.e.* dives) to facilitate inter-study comparison, and will list the minimum data parameters required to answer most management questions. The terms of reference should include at least the following:

a. review the structure of current datasets
b. examine potential biases in data reduction procedures
c. assess usefulness of parameters of currently provided by standard analytical techniques
d. standardize the definition of a dive
e. suggest developments in the analysis of logged data
f. identify critical analytical programs
g. identify common data archiving requirements.

Recommendation: Promote interaction between and within groups analyzing behavior data and groups developing datalogger technology.

Tag Development

The workshop as a whole, as well as this working group, discussed the utility of developing two types of tags, one being a simple tag to record primarily location data, and the second representing a series of more advanced tags to record parameters specific to particular studies. The data loggers used on each of these tags would, in turn, require differing development efforts.

The need for more precise locations was discussed at length, as were the limitations of the present satellite systems available for this. Given these present constraints, the working group discussed the need to develop filtering algorithms to promote better location estimation for fixes with highly variable or unknown confidence limits. This discussion focused on the Argos Class 0 locations, though its implications were more widespread.

This working group proposed developing a modular configured tag for increased flexibility on the parameters to be measured. Several data retrieval options were also discussed, and will likely be dictated by the specifics of each individual project.

Recommendation: Develop a datalogger as a model for the development of a modular and flexibly configured basic tag. The tag should provide location, dive and temperature data. A peripheral device should be developed to provide a high accuracy location option. The group recommends that GPS, LORAN, inertial guidance and/or depth-velocity-bearing technologies be investigated at the basis for this peripheral.

The following data retrieval options should be considered: (1) remote release and retrieval of instrumentation and data; (2) one-way VHF data link; (3) two-way VHF command and interrogation link; and (4) Argos and other satellite data gathering systems

Recommendation: Build an advanced configuration tag that elaborates on the information obtained by the basic tag. This approach would involve intensive studies of key species that are especially amenable to handling and study (for example, bottlenose dolphins, beluga and humpbacks among cetaceans and elephant seals and Weddell seals among deep-diving pinnipeds). This configuration would use specialized sensors focusing on special aspects of diving such as foraging (for example monitoring, swallowing, stomach temperature and/or jaw movement, and the use of still and video photography) or measurement of physiological variables (for example, blood gas/chemistry, core temperature).

Recommendation: Develop filtering algorithms which will aid in the interpretation of location fixes with variable and/or unknown confidence limits. This has particular relevance to the interpretation of Argos Class 0 locations.

Integration of Behavioral and Environmental Data Sets

It was recognized that the satellites used to track and record marine mammal data at present, are the same satellites which routinely collect environmental data, specifically sea surface temperature, turbidity indexes, and sea-ice cover. Earlier satellites also collected ocean color indexes, which were translated to estimates of biological productivity (*i.e.* chlorophyll concentration) and wave height information. Wave height, wind speed and direction, sea level pressure and sea and air temperatures can also be obtained through buoys located along the U.S. coast, operated by the National Oceanic and Atmospheric Administration. This working group recognized the need to correlate the information collected through tagging and tracking studies with oceanographic parameters routinely being monitored by various agencies.

Recommendation: The group recognized the need to integrate marine mammal behavior with oceanic data such as bathymetry, climate, current, acoustic profiles, primary productivity, fisheries, *etc.*, and other aspects of the species under study. These datasets are spread across many agencies in many different formats. **It is recommended** that: (a) a list of appropriate oceanic datasets is compiled; this should include their availability and format; and (b) a study is made of what software/hardware (for example GIS and visualization technologies) is available and most appropriate for displaying and cross-correlating behavior data with oceanic datasets.

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ATTACHMENT A

WORKSHOP AGENDA

February 11, 1992

8:45 - 9:00 am	**Welcome** David Potter, Melbourne Briscoe
9:00 - 9:30	**Review of tagging activities, prior to and since the 1987 workshop** Robert Hofman
9:30 - 9:35	**Overview of data acquisition methods: Satellite, data Loggers, VHF/HF telemetry, acoustic telemetry** Dan Costa
9:35 - 10:30	**Overview of Data Loggers: What is currently available? What is needed?** Roger Gentry
10:30 - 10:45	Coffee break
10:45 - 12:00	**Overview of Satellite Tags: What is available: What has been done? General results? What is needed?** Bruce Mate, William Watkins, Anthony Martin, Jeffrey Goodyear
12:00 - 1:00 pm	Lunch
1:00 - 2:00	**Overview of Acoustic Telemetry: What can be measured? Advantages, results, future?** Mike Fedak, William Watkins
2:00 - 2:30	**Sensors and sensor development** Rod Mesecar
2:30 - 3:30	**Attachment methods: Review and discussion of problems and potential solutions** William Watkins, Bruce Mate, William Medway
3:30 - 3:45	Coffee break
3:45 - 4:30	**Information Transfer Technology: Data throughput, limits to data transmission, status of date compression, new systems development** Paul Howey, Bernie McConnell
4:30 - 5:00	**Location Information: GPS vs. Argos** Stan Tomkiewicz
5:00 - 5:30	**User Needs. What we would like to be able to measure. What is holding us back** Steven Swartz
5:30 - 6:00	**Charge to Working Groups** Carol Fairfield
6:30 - 7:30	Dinner
8:00	Open discussions in meeting room. Adjourn.

February 12, 1992

8:45 - 9:00 am	Working Group assignments
9:00 am - 5:00 pm	Working Groups meet

ATTACHMENT B

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ATTACHMENT C

TAGGING AND TRACKING PROJECTS UNDERWAY OR PLANNED[1]

Russ Andrews, University of British Columbia, Vancouver, B.C., Canada, (604) 822-3377

Species Working with:	Northern elephant seals
Geographic Location:	Ano Nuevo Island, California
Scheduled Field Season:	April-June, September-November
Description of Project:	Attempting to gather basic information on foraging behavior and diving physiology of the northern elephant seal. Plans are to deploy data logger on adult animals for 5- to 7-month foraging trips to sea. Data logger logs depth, swim speed, water temperature, body temperature, heart rate and respiration. Also plan to add sensor to record jaw openings and stomach pH and temperature.

Bud Antonelis, Tom Loughlin, Robert DeLong, Richard Merrick, S. McCline, National Marine Mammal Laboratory, Seattle, Washington, (206) 526-4045

Species Working with:	Steller sea lions, California sea lions, northern fur seals, northern elephant seals, and harbor seals
Geographic Location:	Bering Sea, Gulf of Alaska, eastern North Pacific, coastal waters of western United States
Scheduled Field Season:	1992-1993
Description of Project:	Foraging studies of Steller sea lions using Argos satellite tag (1 to 4 months), conducted in Gulf of Alaska, Bering Sea and North Pacific; migration and foraging behavior of northern fur seals using Argos satellite tag (1 to 4 months) and planned retrievable data loggers (1 to 8 months), conducted in Bering Sea, Gulf of Alaska and eastern North Pacific; foraging studies of California sea lions using Argos satellite tags (1 to 4 months) and retrievable data loggers (1 to 6 months), in California current and coastal waters of California; migration and foraging behavior of northern elephant seals using retrievable data loggers (1 to 10 months) in California current, North Pacific and Gulf of Alaska; and movement patterns of harbor seals using VHF radio tags (1 to 4 months) in coastal waters of Washington.

Robin W. Baird, Marine Mammal Research Group, Victoria, B.C., Canada, (604) 380-1925

Species Working with:	Killer whales
Geographic Location:	Southern Vancouver Island, British Columbia
Scheduled Field Season:	April-May and August-October
Description of Project:	VHF tag attached with a suction cup; delivery by means of a 3 to 4 m pole. Tag includes a TDR for depth of dive. Whales followed while tagged; maximum tag duration is ~10 hrs using a magnesium release mechanism.

Ian L. Boyd, British Antarctic Survey, Cambridge, U.K., 011 44 223 61188

Species Working with:	Antarctic fur seals
Geographic Location:	Southern Ocean
Scheduled Field Season:	1992-1995
Description of Project:	Satellite telemetry of location at the feeding grounds linked to dive data from recoverable TDRs.

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[1] This list includes all projects known to the editors at the time this report was prepared. We recognize that the list may be incomplete.

Richard Chapman, Wildlink, Inc., Brooklyn Park, Minnesota, (612) 424-8349

Species Working with:	Deer, wolves, bears, caribou, others
Geographic Location:	North America
Scheduled Field Season:	Year-round
Description of Project:	Recapture collars for remote immobilization. Technologies include release mechanisms, two-way VHF radio communications, data logging, sensor monitoring, global positioning system models for precise location data gathering.

Susan Chivers, Southwest Fisheries Science Center, La Jolla, California, (619) 546-7093

Species Working with:	Spotted dolphins
Geographic Location:	Eastern tropical Pacific Ocean
Scheduled Field Season:	Fall
Description of Project:	November 1992: to radio tag spotted dolphins in conjunction with sonic tagging of yellowfin tuna. Fall 1993: satellite tag, and perhaps radio tag, spotted dolphins; primary sensor for location but probably will also include depth and temperature; 2 to 3 months longevity.

Daniel Costa, University of California, Santa Cruz, California

Species Working with:	Australian sea lions, northern elephant seals
Geographic Location:	Kangaroo Island, South Australia; central California
Scheduled Field Season:	Year-round
Description of Project:	Research on sea lions centers on seasonal changes in foraging behavior and examination of foraging energetics and ecology of both species.

Marilyn E. Dahlheim, Tom R. Loughlin, National Marine Mammal Laboratory, Seattle, Washington, (206) 526-4020

Species Working with:	Killer whales
Geographic Location:	Alaska
Scheduled Field Season:	Summer/Fall 1993
Description of Project:	Satellite tag with minimum longevity of 6 to 9 months Objective: to determine overall distribution of killer whales in Prince William Sound and adjacent waters during September-March.

Dave Douglas, U.S. Fish & Wildlife Service, Anchorage, Alaska, (907) 786-3473

Species Working with:	Marine and terrestrial mammals and birds
Geographic Location:	Anchorage
Scheduled Field Season:	Ongoing
Description of Project:	GIS and statistical program to process and analyze Argos data; also performance testing of a 30-g PTT with voltage and time sensors, 60+ days.

Mike Fedak, Sea Mammal Research Unit, Cambridge, U.K., 011 44 223 311354

Species Working with:	Gray, harbor, southern elephant and hooded seals; beluga whales, southern sea lions
Geographic Location:	Arctic, North Sea, west Atlantic Ocean, Antarctic
Field Season:	Periods in spring, summer, autumn and winter
Description of Project:	Using data loggers and Argos tags to record position, depth, velocity; 75 kHz acoustic tag for depth, velocity, temperature, and heart rate; VHF tag to record presence with auto-direction finding and logging.

Lars Folkow, University of Tromso, Tromso, Norway, 47 83 44792

Species Working with: Minke whales
Geographic Location: Norwegian Sea, Barents Sea
Scheduled Field Season: July/August 1992
Description of Project: Energetics studies: calculations of energy expenditure based on recording of respiratory frequency. VHF tags are used to determine surfacing rates (which correspond to the respiratory frequencies) at different levels of activity; Tag is attached in blubber, transmitter on the body surface combined with acoustic transmitter with depth sensor. Anticipated tag longevity, several weeks.

Mark Fuller, U.S. Fish & Wildlife Service, Laurel, Maryland, (301) 498-0282

Species Working with: Peregrine falcons
Geographic Location: Greenland
Scheduled Field Season: Year-round
Description of Project: Conventional, pulsed transmitter with activity sensors will be placed on breeding adults in 1992; aerial tracking will provide location estimates for delineation of home range and description of habitat use.

Species Working with: Gyrfalcons
Geographic Location: Greenland
Scheduled Field Season: Year-round
Description of Project: Coded transmitter will be used on gyrfalcons in 1992 to study their survival and philopatry in subsequent years.

Species Working with: Sea eagles
Geographic Location: North Pacific Rim
Scheduled Field Season: Year
Description of Project: PTTs weighing 55 to 135 g are used on adult and fledgling eagles to study dispersal, migration, and home range. Sensors used include battery voltage, temperature and activity (mercury switch).

Species Working with: Waterfowl
Geographic Location: Eastern North America
Scheduled Field Season: Year-round
Description of Project: Planned use of PTTs to study migration routes of waterfowl that winter in the mid-Atlantic region of the United States.

Gerald Garner, Steve Amstrup, U.S. Fish & Wildlife Service, Anchorage, Alaska, (907) 786-3473

Species Working with: Polar bears
Geographic Location: Chukchi, Bering and Beaufort Seas
Scheduled Field Season: March - May
Description of Project: Argos PTT, activity/voltage, temperature, 1 to 2 years.

Roger L. Gentry, National Marine Mammal Laboratory, Seattle, Washington, (206) 526-4032

Species Working with: Northern fur seals
Geographic Location: Commander Islands
Scheduled Field Season: August 1993
Description of Project: Deployment of conventional TDRs to measure prey capture rate through jaw movements and changes in stomach temperature, as well as measuring location and swim speed.

Jeffrey Goodyear, Victoria, B.C., Canada, (604) 370-1784

Species Working with: Humpback whales, right whales
Geographic Location: Cape Cod, Massachusetts, and Bay of Fundy
Scheduled Field Season: Fall 1992
Description of Project: Study of migration rates and routes; exchange between feeding grounds, diel behavior patterns on feed grounds. Sensors: dive profiles, water temperature, number of dives, average dive duration, location using Argos & VHF. Longevity, up to several months.

Jim Harvey, Moss Landing Marine Laboratory, Moss Landing, California, (408) 755-8669

Species Working with: Harbor porpoise, harbor seals
Geographic Location: Monterey Bay, California
Scheduled Field Season: Year-round
Description of Project: VHF tags attached to pelage of harbor seal head; possibly TDRs on back of harbor seals. VHF tags on dorsal fins of harbor porpoise (proposed).

Sue Hills, Dave Douglas, U.S. Fish & Wildlife Service, Anchorage, Alaska, (907) 786-3473

Species Working with: Walrus
Geographic Location: Bering and Chukchi Seas
Scheduled Field Season: April - October
Description of Project: Argos PTT, Telonics unit; saltwater sensor, 2 to 6 months

Gerald Kooyman, Scripps Institution of Oceanography, La Jolla, California, (619) 534-2091

Species Working with: California sea lions, Weddell seals, New Zealand fur seals, emperor penguins
Geographic Location: California and Antarctica
Scheduled Field Season: October - January 1992
Description of Project: Behavior and physiology of emperor penguins, physiology of diving in California sea lions. Microprocessor-controlled TDRs and physiological variables; satellite tracking of emperor penguins.

Burney Le Boeuf, University of California, Santa Cruz, California, (408) 459-2845

Species Working with: Elephant seals, Guadalupe fur seals
Geographic Location: California and Gulf of Alaska; Patagonia, Argentina; Guadalupe, Mexico
Scheduled Field Season: Elephant seals, year-round; fur seals, summer
Description of Project: Northern elephant seals: study of migratory path, foraging areas and diver patterns using Wildlife Computers Mark III TDR with geolocation; attached with marine epoxy and recovered on rookery; tag and attachment duration, 8+ months; Special studies using translocation paradigm, *e.g.*, heart rate, swim speed, doubly-labeled water, and using custom-made sensors; plan to monitor swallowing and stomach temperatures as reflection of foraging. Southern elephant seals: same study as noted above using only female animals; no special studies. Guadalupe fur seals: same studies as northern elephant seals; deployment of 6 TDRs on lactating females. Geolocation from light sensors.

Jon Lewis, Alaska Department of Fish and Game, Anchorage, Alaska, (907) 267-2419

Species Working with: Steller sea lions, harbor seals
Geographic Location: Gulf of Alaska; Prince William Sound
Scheduled Field Season: February - September
Description of Project: Both studies use Wildlife Computer's half-watt satellite-linked TDRs. Approximately 25 Steller sea lions and 20 harbor seals will be tagged. Tags will fall off during molt. Aerial surveys and VHF relocation will be used as tools for close observation.

Jon Lien, Memorial University of Newfoundland, St. John's, Nfld., Canada, (709) 753-5495

Species Working with: Humpback whales
Geographic Location: Newfoundland and Labrador
Scheduled Field Season: June-August
Description of Project: Humpbacks caught accidentally in fixed, inshore fishing gear are available for tagging, and testing and calibration of sensors and attachment techniques. No specific tagging program is planned. Times and locations of entrapments are predictable.

A.R. Martin, Sea Mammal Research Unit, Cambridge, U.K., 011 44 223 311354

Species Working with: Belugas and narwhals
Geographic Location: Canadian Arctic
Scheduled Field Season: July-August 1992-1996
Description of Project: Tags used are "SMRU" type, twin tubes on a saddle attached to dorsal ridge by means of inert plastic pins. Male narwhal tags are single tube, tusk-mounted. Potential longevity >6 months Sensors: swim velocity, emergence, depth. temperature. Data: position, detailed dive profiles and swim velocities during dive, 24-hour summaries of dive duration and maximum depth. Planned deployment: 15 in 1992, 28 in 1993 and 30 in 1994.

Bruce R. Mate, Oregon State University, Newport, Oregon, (503) 867-0236

Species Working with: Sperm whales
Geographic Location: Gulf of Mexico
Scheduled Field Season: September-October 1992, January-February 1993
Description of Project: Argos tags, surface-mounted with dive duration and depth and temperature summaries; also possibly small location-only tag.

Species Working with: Bowhead whales
Geographic Location: Beaufort Sea
Scheduled Field Season: August-September 1992
Description of Project: Argos tags, surface-mounted with dive duration and temperature (possibly depth).

Species Working with: Fin and blue whales
Geographic Location: Sea of Cortez
Scheduled Field Season: Spring 1993
Description of Project: Argos - Undetermined (proposed)

Species Working with: Bottlenose dolphins, pilot whales
Geographic Location: Hawaii; Florida; Gulf of Mexico
Scheduled Field Season: 1992/1993
Description of Project: Help with Navy tests of dorsal fin saddle attachments and release of "captive," caught or stranded animals; tag bottlenose dolphins in localized populations.

Robert Matthin, New Zealand Ministry of Agriculture & Fisheries, Wellington

Species Working with:	New Zealand fur seals, sperm whales
Geographic Location:	Open Bay Isle and Kaiboura, New Zealand
Scheduled Field Season:	Year-round
Description of Project:	Examination of seasonal changes in diving patterns of New Zealand fur seals; planned studies on sperm whales.

Tom McCabe, Dave Douglas, U.S. Fish & Wildlife Service, Anchorage, Alaska, (907) 786-3473

Species Working with:	Caribou and musk oxen
Geographic Location:	Northeastern Alaska; northwestern Canada
Scheduled Field Season:	On-going
Description of Project:	PTTs, activity and temperature, 1 to 1-1/2 years.

Bernie McConnell, Sea Mammal Research Unit, Cambridge, U.K., 011 44 0223 311354

Species Working with:	Southern elephant seals; gray, harbor seals; southern sea lions; beluga and narwhal whales
Geographic Location:	Canadian Arctic; Norway; United Kingdom; Antarctica
Scheduled Field Season:	February - April 1992
Description of Project:	Development of satellite relay data loggers to relate pelagic behavior of marine mammals in the oceanic environment. The architecture and software of our systems are flexible, allowing deployment on many species. Subminiature version expected by end of 1993. Standards sensors: depth, velocity, diving. Life dependent on animals' behavior but 150 days at 100% duty cycles has been obtained (40-40 uplinks/8 to 10 locations per day).

Paul E. Nachtigall, Naval Ocean System Center, Kailua, Hawaii, (808) 257-5256

Species Working with:	Bottlenose dolphins, false killer whales, Risso's dolphins
Geographic Location:	Hawaii
Scheduled Field Season:	Ongoing
Description of Project:	Study of effects of low-frequency sounds on behavior of cetaceans.

Yasuhiko Naito, Natl. Institute of Polar Research, Tokyo, Japan, (03) 3962-4711

Species Working with:	Pinnipeds, penguins, porpoise, sea turtles
Geographic Location:	Central California (northern elephant seals), Antarctica (Adelie penguins), Japan (harbor porpoises, loggerhead turtles)
Scheduled Field Season:	1993/1994
Description of Project:	Northern elephant seal: diving behavior study using TDRs, SVRs (working with Dr. Burney Le Boeuf); Adelie penguin; diving and feeding behavior using micro-data logger with depth, light intensity, feeding sensors at Davis Station, Antarctic with Dr. Robert Graham; Harbor porpoises: diving behavior study using TDRs with releasing system and radio-location system (VHF) with Dr. Seiji Ohsumi and Dr. Akito Kawamura; Loggerhead turtle: diving and physiological study using micro data logger with depth, velocity, temperature sensors, in Japan, with Dr. Itaru Uchida and Dr. Wataru Sakamoto.

Sharon Nieukirk, Oregon State University, Newport, Oregon, (503) 867-0202

Species Working with: Right whales, bottlenose dolphins, bowhead whales, sperm whales
Geographic Location: Arctic; northwest Atlantic; Gulf of Mexico
Scheduled Field Season: August 1992 (Arctic); September 1992 and January 1993 (Gulf of Mexico)
Description of Project: Argos-linked satellite tag; sensors collect dive duration, number of dives, summary of dive information for 3-6 hour periods.

Guy Oliver, University of California, Santa Cruz, California, (408) 429-5342

Species Working with: Elephant seals
Geographic Location: Monterey Bay, California
Scheduled Field Season: Spring and fall
Description of Project: Translocation of elephant seals from Ano Nuevo to various locations of Monterey Bay will continue to be used to investigate physiological aspects of diving and foraging. VHF radios and TDR (Wildlife Computer Mark III) are consistently deployed. Expect to test temperature and pH sensors, which are swallowed and transmit data to data logger. Proposed attachment of TV camera to seals to transmit signals via microwave link as animals dive and swim back to Ano Nuevo. Attachments/deployments are short, about 1-15 days.

Brent S. Stewart, Hubbs-Sea World Research Institute, San Diego, California, (619) 226-3870

Species Working with: Northern elephant seals, harbor seals, California sea lions, Baikal seals
Geographic Location: Northeast Pacific, Lake Baikal, U.S.S.R.
Scheduled Field Season: Year-round
Description of Project: Habitat use and foraging ecology of North Pacific pinnipeds, using light-level based TDR locating instruments to document migrations and diving patterns and habitat used; satellite-linked RF transmitters with data loggers; sensors, pressure, SST and water column temperature, conductivity sensor; UHF transmitters, aerial tracking habitat patterns relocation for recapture of animal or released instrument. In Lake Baikal ecosystem, studying impact of human activities on seal abundance, distribution, and foraging success. Tags used: satellite-linked data loggers and transmitters; Sensors: pressure, conductivity, for dive duration and depth and surfacing patterns locations through Argos.

Warren E. Stuntz, National Marine Fisheries Service, Pascagoula, Mississippi, (601) 762-4591

Species Working with: Loggerhead turtles
Geographic Location: Northern Gulf of Mexico
Scheduled Field Season: July 1992 - August 1994
Description of Project: Study of relationship between sea turtles and oil platforms in the northern Gulf of Mexico using a modified loran-C radio tag with an estimated longevity in excess of one year.

Peter L. Tyack, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, (508) 548-1400

Species Working with: Bottlenose dolphins
Geographic Location: Sarasota, Florida
Scheduled Field Season: June 1992
Description of Project: Logging level and frequency of vocalizations in temporarily restrained wild or captive bottlenose dolphins in order to identify which animal is vocalizing. Typical attachment time: one hour.

Douglas Wartzok, University of Missouri, St. Louis, Missouri, (314) 553-5898

Species Working with: Ringed seals
Geographic Location: Resolute Passage, Cornwallis Island, Northwest Territories
Scheduled Field Season: 25 March - 30 May 1992 and 1993
Description of Project: Tag type, acoustic; sensors, pressure; longevity, three months. The depth-modulated acoustic pinger is glued to the seal's pelage via a 15cm trailing line that keeps the acoustic transducer away from close contact with the seal's body. Seals are tracked within range (1 km) of a hydrophone array established on the sea ice. Multiple seals can be tracked in real time to establish habitat use patterns and behavioral interactions.

William Watkins, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, (508) 457-2000, ext. 2571

Species Working with: Sperm whales
Geographic Location: Southeast Caribbean
Scheduled Field Season: May and/or October
Description of Project: Cruises scheduled; if tag development funds available, the tagging would be included to provide: identification of individuals; underwater and at-surface tracking; correlation of vocalization with behavior; reactions to environment, low-frequency sounds, etc.

Randall Wells, Chicago Zoological Society, Brookfield, Illinois, (708) 485-0263, ext. 375

Species Working with: Bottlenose dolphins
Geographic Location: Florida
Scheduled Field Season: Undetermined
Description of Project: Developing plans to satellite-tag bottlenose dolphins in offshore waters in association with Bruce Mate.

Terrie M. Williams, Naval Ocean System Center, Kailua, Hawaii, (808) 257-1614

Species Working with: Bottlenose dolphins, pinnipeds, sea otters
Geographic Location: Primarily in Hawaii; also Alaska and California
Scheduled Field Season: Year-round in Hawaii; June-August elsewhere
Description of Project: Presently deploying TDRs on semi-captive bottlenose dolphins for short-term (one day) studies; planned work includes deploying satellite microprocessor on small, free-ranging odontocetes to study physiological/environmental correlations.

ATTACHMENT D

REFERENCES CONCERNING CETACEAN TAGGING AND TRACKING

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