Report to the Marine Mammal Commission on the

Small Cetacean Electronic Tag Attachment Workshop

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BACKGROUND

Over the past decade, there has been an increase in the number of telemetry devices deployed on small cetaceans. Some of these devices are attached using non-invasive techniques, such as suction cups. Other approaches require the capture and handling of individuals and the surgical attachment of tags. These latter tags typically consist of satellite-linked and/or VHF transmitters that provide information on longer-term movements and behavior. The increased frequency with which such long-term tags are used may be attributed to reductions in their size and cost, and possibility of purchasing these transmitters off the shelf, in a configuration that is ready for deployment. These tags provide information that is not obtainable in other ways and are often used to address important biological questions, often related to conservation and management.

These methods are likely to be used with increasing frequency in the future, given the pressing need for the information generated by such techniques. Unfortunately, the results of these studies often do not meet expectations, because most tags transmit for shorter periods than expected. Premature failure is usually attributed to a malfunction in the attachment mechanism, in the transmitter, or both. Transmitter failure does not directly affect the tagged animal, but attachment failure can have serious consequences on the health and well being of an individual. In recent studies of several species, attachment failure has been frequent and potentially injurious. Although these transmitters were configured and attached using “accepted” methods, subsequent observation has revealed serious fin trauma and disfigurement. Little systematic work has been done to determine the kinds of attachments that are appropriate for planned deployments of different durations. In the absence of such data, an increasingly common approach has been to maximize duration of attachment without a contingency plan to monitor the effects of the attachment on the animal, and without an option for re-capture and removal of the tag should conditions warrant.

Researchers using these techniques have had few opportunities to share experiences and agree to a way forward. The present workshop was designed to bring together leading experts to share recent experiences and, importantly, agree to a set of recommendations regarding the use of electronic tags on dolphins, porpoises and other small cetaceans.

OBJECTIVES

The specific objectives of the workshop included the following:

1) review currently available attachment techniques and materials
2) review recent observations of the effects of electronic tags on:
    - a. bottlenose dolphins
    - b. spotted dolphins
    - c. beluga whales
    - d. botos
    - e. harbor porpoises
    - f. killer whales
3) review effects of attachment on health & welfare
4) agree to a set of acceptable techniques for attachment and follow-up
5) discuss which age and sex classes are acceptable subjects for tagging
6) review future research & funding possibilities

7) prepare a list of concrete recommendations for future tagging projects
8) publish a document that describes this review as an NTIS Report or NOAA Tech Memo and publish a summary of this work as review paper in *Marine Mammal Science*

It is particularly important to publish a set of recommendations for attachment techniques, materials and procedures, as no such information exists today. None of the relevant scientific societies (SMM, ECS, ASM) have guidelines that pertain to this research.

WORKSHOP LOGISTICS AND REPORT

The workshop was convened at Mote Marine Laboratory, in Sarasota, Florida, on 11-12 June 2003. Sarasota was selected to take advantage of the presence of many workshop participants, already in the area at this time due to residency or for research or teaching reasons. Twenty-five experts on small cetaceans, including 21 biologists and four veterinarians, participated in the workshop (see appendix). Participants came from the United States, United Kingdom, Denmark, and Brazil. Randall Wells, of Mote Marine Laboratory, served as the workshop facilitator, and Tara Cox, of the Marine Mammal Commission, served as rapporteur. The workshop agenda (see appendix) included initial presentations by invited participants on dorsal fin morphology and results of recent experiences with radio transmitter attachments on small cetaceans. The remainder of the workshop involved discussions of methodology and development of recommendations. The report of the workshop includes: 1) a general workshop overview, 2) summary of recommendations, and 3) contributed background papers and summaries of presentations. It should be noted that recommendations presented below represent majority views, but are not necessarily consensus opinions.

SMALL CETACEAN TAG ATTACHMENT: CURRENT TECHNIQUES AND CONCERNS

Introduction

Since the late 1960's, tagging has been used extensively with small cetaceans to identify individuals, track movements, and to telemeter other information about animal behavior and environment parameters (*e.g.*, Evans *et al.* 1972, Irvine and Wells 1972, Gaskin *et al*. 1975, Irvine *et al*. 1981, Würsig 1982, Read and Gaskin 1985, Scott *et al*. 1990, Read 2002, Wells 2002). Tags are typically attached to the dorsal fin or the dorsal ridge of the cetacean. These regions of the body are regularly above the water's surface, allowing view of the tags, or facilitating signal transmission. Tag attachment techniques vary with the kind of tag used, which in turn is usually determined by the scientific questions being addressed. In some cases, the necessary data can be collected during brief monitoring periods, which allows the use of a temporary attachment that releases from the animal in hours or days. In many cases, however, the research objectives require data collection over longer periods, on the order of weeks, months, or sometimes even more than a year. To date, all such long-term tagging has required the use of surgical attachment techniques, typically involving one or more pins that penetrate the dorsal fin or ridge.

Much important information has been gained through the use of surgically-attached tags, but it has also been evident since the early stages of tag development that such attachment techniques have the potential to injure study animals. Progress in reducing the potential of injury has come from dedicated research in the field and laboratory, together with studies of the functional morphology of dorsal fins (*e.g.*, Irvine *et al*. 1982, Scott *et al.* 1990, Rommel *et al*. 1992, 1993) and a small number of workshops dedicated to this subject (NOAA 1992). This work has yielded incremental changes in design and attachment methods, but the approach has been less than perfect. The relatively small numbers of tags deployed in each study, and the even smaller number of cases in which subsequent observations have been made to allow evaluation of attachments, has meant that progress has been slow. The lack of a systematic approach to tag deployment and follow-up monitoring has meant that conclusions about designs and factors affecting them are often made on the basis of anecdotal observation. We are not aware of a single dedicated study with an adequate statistical design and sufficient sample size that has addressed questions of tag design and attachment. As a result, some tag designs deployed in recent years still result in significant injury.

Recognizing the need to expedite the process of developing acceptable tag attachment designs, and to avoid repeating previous failures, a workshop was convened to identify the current state of our knowledge about attachment of tags to small cetaceans, and to develop recommendations. In June 2003, a group of veterinarians and biologists with recent experience with tagging, or detailed knowledge of dorsal fin anatomy, met at Mote Marine Laboratory, in Sarasota, Florida. The following sections summarize the views of the majority of participants, and identify critical data gaps.

The application of radio-tagging and tracking to a biological or management question involves evaluation of trade-offs. The potential risks to individuals from tagging must be weighed against the risks to populations through continued ignorance if the tagging and tracking are not done. Most workshop participants agreed that *no* tagging work should be carried out on small cetaceans before a thorough evaluation of its justification and methodology. All tagging involves stress and some risk to the study animal, and almost all work of this type requires that the animal be first captured and restrained, which carries further risk and stress to both the animal and the capture team. These risks include the possibility of the death of the study animal, although this outcome is rare.

Workshop participants agreed that any tagging study should first define the question or hypothesis to be addressed, then to determine the methodology that could provide the answers with minimum impact on the population of interest. The benefits of tagging, in terms of knowledge gained, should be evaluated against the potential costs to both individuals and populations. The risk and stress to each tagged animal should be minimized and the tagging procedure should be carried out on no more individuals than is necessary to answer the question or test the hypothesis.

Experience has shown that cetacean species react in widely different manners particular capture or tagging procedures. Workshop particpants, therefore, recommended that the assessment of any proposed study must be specific to the circumstances and species involved. Generally, however, less risk and stress is associated with shorter deployments, and those that do not involve capture. In some cases, research questions may be answered satisfactorily through means that do not require capture and surgical attachment of tags. In all cases, research teams undertaking tagging efforts should include researchers with tagging experience.

In general, the group agreed that there is a need for guidelines to help designing research programs and to facilitate permit application review.   It was recognized that, in the absence of systematic efforts to develop such guidelines, the collective recent experience of experts in the field can help to fill this gap, until such time as appropriate data become available. In the meantime, efforts should be made to systematically collect data on tag durability, tag size, location of attachment, type of attachment, and effects on the animals, including detailed documentation of health and stress parameters and tissue damage. To this end, the group recognized the importance of monitoring the animals themselves as opposed to simply tracking signals, to determine how and why tags and attachments succeed or fail, and how these tags affect the animals. There was also recognition of the value of a centralized database for compiling these data. The following summarizes discussions of specific topics relative to tag attachment.

Duration of Tag Attachment

Since the first deployments of radio tags, a primary concern has been to develop safe attachment methods that allow long-term deployment. Some recent deployments have exceeded 12 months, as reported by Hanson and Hohn at this workshop, so we are now faced with the additional question of how to ensure that tags are shed once they have served their purpose. As longer deployments become possible, it becomes increasingly important to match the duration of tag attachment with the specific research questions, minimizing the burden on the animal beyond the time of desired data collection.

Attachment Techniques, Materials, Number of Attachment Points

Most of the tag attachments discussed at the workshop involved the application of pins through dorsal fins or in the case of monodontids which lack dorsal fins, through the dorsal ridge. Consideration of dorsal fin anatomy led workshop participants to several precautionary recommendations:

(1) minimize the involvement of major structural elements of the fin,
(2) minimize damage to blood vessels by minimizing the number of attachment sites and using non-invasive imaging to locate blood vessels prior to penetration, or probing with a hypodermic needle to determine arterial positions,
(3) study the species' anatomy in advance of tag design
(4) allow flexibility into design of the tag and attachment system, to respond to blood vessel location variability (*e.g.*, multiple pin placement sites) (see appendix).

Given the role of the dorsal fin in thermoregulation of the reproductive system (Rommel *et al.* 1993), concerns were raised about tagging adult females, but no consensus was reached on this point.

One of the primary concerns with tag attachment involved migration of the package and subsequent tissue damage resulting from movement of attachment pins. Typical migration involved upward and then backward movement, perhaps from an increased drag load at the air-water interface, leading to tissue breakdown. The number of attachment pins used generated much discussion, but so very few empirical observations have been made on similar tag designs with varying number of attachment sites that it was not possible to evaluate this factor. In general, the minimum number of pins necessary to secure the package to the fin should be used. This is tag- and size-dependent, but typically one to four pins are used. With more pins, there may be less migration, but with more pins, there is a greater chance of penetrating a blood vessel or losing pins at different times and therefore increasing torque/motion.

Currently, three kinds of pin materials are used: nylon, delrin, and surgical-grade titanium. Pin materials have been selected on the basis of: (1) a desire for pin flexibility *vs*. rigidity, 2) a desire to allow breakaway of the transmitter package under some circumstances, and 3) a desire to promote healing of the attachment site and prevent infection (Geraci et al. 1985). There was no consensus among workshop participants regarding the role of pin flexibility/rigidity in migration. Some researchers use plastic pins because they believe that their flexibility reduces pressure on fin tissues, while others believe that greater rigidity limits movement of the package. More observations are needed to resolve this issue. Most participants agreed that if a great deal of torque is applied to a tag (*e.g.* through entanglement) the pins should shear before the fin tissues shear. Therefore, having an extremely strong attachment is not always the best option, and the use of plastic pins may provide an effective breakaway mechanism. Alternatively, some kind of a breakaway mechanism should be built into the package if stronger pins are used.

Workshop participants concluded that threading on the pins is an important consideration. Pins should be smooth where they are in contact with fin tissue, and threaded only on the ends beyond the fin. Excess pin length should be trimmed to minimize drag and potential for entanglement or contact with con-specifics. It was suggested that internal threads could be added to the tag to reduce the need for external nuts and threading.

Alternatives to pins were discussed. Previous reports have recommended that no body belts or harnesses should be used for long-term applications (*e.g.* NOAA 1992). These systems are only appropriate in very short-term applications when dealing with animals that are acclimated to intensive handling. Suction cup attachments can be very useful for short-term deployments (up to 48 hours), but the effects of longer-term deployments of these 'non-invasive' methods have not been evaluated and need to be investigated.

Size, Positioning, and Configuration of Tag Packages

To date, deployments have involved a variety of tag sizes and positions on the dorsal fin. The primary considerations are to reduce the overall size of the tag and thus its: (1) drag, (2) footprint (amount of coverage of the fin surface), (3) volume, and (4) mass. The minimum size of the tag (mass and volume) will be dictated by electronics and housing, but consideration must be given to hydrodynamic sculpting and, perhaps, the need to balance package size on both sides of the fin. Most researchers agreed that the size of the tag package should be minimized. No consensus was reached regarding the desirability of balancing tag volume/drag on each side vs. minimizing tag size with a single side mount; both approaches have had mixed success. In general, it was considered desirable to minimize fin surface coverage and maximize water flow over the fin for thermoregulatory and tissue health reasons. Tag designs involving mounting on the leading edge of the fin were thought to: (1) create too much drag, (2) likely not reduce probability of migration, and (3) may interfere with social interactions; therefore such mounts are not recommended. Better efforts should be made to record tag mass, volume and footprint to allow future evaluation of tag success and impacts.

Tag Release Mechanisms

Tags should be designed to release from the dolphins about the time of battery drainage – there is no good reason for transmitter packages to remain on the animals following cessation of transmission. Participants recommended that once one linkage fails, all linkages should fail, allowing the tag to be jettisoned. If simultaneous release of all pins is not feasible, then attachments should be designed to minimize damage by placing primary attachment pins in strategic positions. Currently, most release mechanisms rely on passive galvanic action involving corrodible nuts and release times are not well-controlled. There is a strong need for research on active release mechanisms; this research should involve engineers with experience in marine environments who will be able to take into account the effects of variation in salinity, water temperature, and water flow.

Effects of Tag Attachment on Health and Welfare

Overall Health – Any candidate for tagging should be healthy, at least as evaluated visually by a biologist or veterinarian with extensive experience with the species. If possible, blood samples should be taken and their analyses be considered prior to tagging, but this is rarely possible in the field. Animals should be monitored carefully during the tagging operation, including respiration, heart rate, and temperature. If an animal begins to display any indications of adverse response to capture or tagging, the procedures should be aborted immediately, and the animal should be returned to the water and supported until it returns to full functionality. Indications of adverse responses include: breath-holding, prolonged opening of the blowhole, lack of ocular response, arching of the head and tail, and lack of responsiveness. The researcher should be ready for all contingencies; if an animal dies during capture or handling, the researcher should be prepared to conduct a full post-mortem examination, including sample collection. Appropriate expertise during tagging is critical. A person experienced with capture and tagging of small cetaceans and with health of the specific species *must* be present to monitor the animal's condition. Ideally a veterinarian with such specific expertise should be present during such procedures.

Sterilization – All materials involved in attachment should be sterilized – corers, pins, washers, nuts, etc. Cold sterilization with glutaraldehyde with rinsing can be done in the field, although gas sterilization may be preferable.

Anesthesia – There was disagreement among participants as to whether observed responses to the surgical procedures used to insert attachment pins resulted from pain or a reaction to the noise or pressure from the drill, and therefore whether anesthesia (*e.g.*, lidocaine) is useful or desirable. The effects of tag attachment on nerves in the dorsal fin is not known, and should be investigated. If there is pain, is it only transitory and associated with the preparing holes for the pins, or does it continue after the tag is attached? The enervation of the dorsal fin is not well known, nor is it known if nerves affect vasculature.

Holes for Pins – Potential pin locations should be probed first with a hypodermic needle to check for blood vessels. A long needle can also be used to help line up the coring tool. Holes should be cored with a sterilized cork-boring cutter or equivalent.

Swelling and Pressure Necrosis -- Swelling around the attachment sites is likely to occur and presents several potential problems. An inflammation response to pin installation and tag attachment is likely to occur, although research is needed to determine if the edema is from trauma or infection. Thermal imagery at intervals following attachment would be useful, as would sampling of the inflammation sites during re-capture operations. Researchers should resist the temptation to over-tighten tags and instead allow space for swelling from pressure of hole boring or contact with the tag. Quantification of the clearance is difficult; research is needed to determine appropriate clearance. Some researchers have used easy movement of a playing card between the tag and fin as a gauge of clearance, but others have determined that this is not adequate. The backing/padding material of a tag will affect the contact between tags and fins; neoprene will compress with pressure.

Appropriate Sex and Age Classes for Tagging

Researchers should be cognizant of the relative risks to animals of different age, sex, and reproductive classes and should strive to balance the risks to the individuals relative to the knowledge benefits derived from the research. Pregnant females may be at higher risk from capture stress and damage to dorsal fin than other classes due to the importance of the dorsal fin for regulating the temperature of the fetus (Rommel *et al*. 1993). Comparative data from terrestrial species suggest that these risks exist throughout pregnancy, but the greatest risk to these individuals occurs during the early stages of pregnancy and during the third trimester. If pregnant females must be tagged to address specific research questions, options for tag design should be explored to minimize the potential impact on the female and her developing fetus.

When possible, researchers are encouraged to identify pregnancy prior to tagging, for example, through ultrasound, and monitor the condition and body temperature of the female during tagging, but in some cases these activities may be of greater risk than the tagging itself. As is the case with all capture and handling, special care and precaution should be taken when tagging extremely young animals (dependent calves).

Observation, Follow-up Monitoring and Intervention

In spite of the widespread application of attachment tags, workshop participants agreed that all deployments should be considered experimental. Therefore, whenever possible, follow-up monitoring of tags and the animals should be an integral component of the research plan. Direct observations of tagged animals not only provide information on the condition of the tag and health of the animal, but also allow opportunities for validation of data telemetered by the tag. Follow-up monitoring may be more feasible with coastal species than pelagic species, but many tags offer options for remotely monitoring the function of the tag itself, and for monitoring the behavior (*e.g*., surface time) of the animal. It is incumbent upon researchers to conduct these observations and publish the results of their follow-up monitoring in the peer-reviewed literature – without such compilations, tagging will always be considered experimental.

Follow-up monitoring can also provide opportunities to intervene in cases where tags are clearly adversely impacting the dolphins. Most workshop participants believed that researchers have an ethical obligation to closely monitor animals they tag and intervene when problems result from the tag. However, the workshop participants did not reach consensus regarding criteria for determining when intervention is required. They recommended that a group be established to develop guidelines for identifying when it is most important/appropriate for intervention to occur. The group suggested that a central depository for compiling findings of follow-up monitoring and intervention be established.

Recognizing the importance of follow-up monitoring, when possible, researchers should include follow-up expenses in their budget development, and funding agencies should put a high priority on funding studies with dedicated follow-up efforts.

Research Priorities

The use of electronic tags is a very powerful research tool. More than 30 years of tagging efforts have demonstrated both the value of the approach and the risks to the animals. Despite this long history, users of this research tool still consider its application to be experimental. To minimize the risks to animals, a considerable amount of new research is needed on factors that affect attachment of tags to dolphins. Recommended research topics are listed below, as prioritized by the workshop participants (LOW, MEDIUM, and HIGH priority).

Among the most important questions is the relative importance of footprint *vs*. drag *vs*. volume *vs*. mass in tag package design. For almost all research topics, the question of “How many animals is enough?” is a critically important question - power analyses should be performed in advance of these studies. Logistics for the studies will be challenging. In most cases, efforts will require evaluating tag and attachment design in tandem with collecting needed biological information. However, stranded dolphins in the final stage of rehabilitation may also provide important opportunities for monitoring effects of tags and attachments for several weeks prior to release, and also during follow-up monitoring. The effects of dummy tags on attachment sites (healing, swelling) could be monitored both visually and with thermography.

Attachment Research

Active release mechanisms (as opposed to galvanic release) HIGH
Passive, simultaneous release of multiple pins HIGH
Breakaway designs (either pins or packs) HIGH
Factors influencing tag migration HIGH
- Pin diameter, pin placement, # of pins, etc. HIGH
- What are costs and benefits of wrap-around, 2-sided and 1-sided? HIGH

Innovative attachment techniques other than nuts and bolts HIGH
Factors influencing longevity of attachments HIGH
- Ideal number, placement of pins, pin diameter

Hydrodynamic testing HIGH
- Flow characteristics over control fins – standard (already done?)
- Disruption of flow

Completely internal tags MEDIUM
Controlled studies of tightness MEDIUM
Can you build instrumentation into pack to monitor status of pack? MEDIUM
Pins with antibacterial timed release LOW
Size of drilled hole vs. pin diameter LOW

Follow-up Monitoring Research

Why did tag fail? – attachment vs. transmitter? HIGH
Can you make generalizations about sex/age/reproductive condition considerations? MEDIUM

Biological Research

Thermal imagery of pin sites at set time intervals after pin placement HIGH
- Studies of captives/rehab animals

Energetic costs of tags HIGH
- Drag vs. volume vs. mass vs. surface area

Tissue damage pressure threshold (and then design pins to shear at less pressure) HIGH
Tissue rejection; retention of pins – look at natural biological actions, e.g. parasites have figured it out – cooperate with researchers looking at natural chemicals; natural glues HIGH
Map nerve structure in dorsal fin MEDIUM
- Function of nerves, i.e. do they affect vasculature
- Effectiveness of anesthesia and/or ice
- Best location for administering/applying anesthesia or ice

Long-term thermal effects (e.g. long-term version of heat flux studies) – revascularization? MEDIUM
Distinguishing between acute and chronic effects MEDIUM
Behavioral effects of tags LOW
- Respiration rates
- Dive durations
- Surfacing durations

Dive depths
Swim speeds
Swimming pattern
Movement pattern

Social effects of tags LOW

Number of associates
Nearest neighbor distance
Specific associates
Nature of interactions

<u>*General Research*</u>

Capture/re-capture with health assessments to examine effects, both to health and from attachment (*e.g.,* Wells *et al.* 2004). Many of the above research questions could be incorporated into this approach in a massive experiment. EXTREMELY HIGH

Coordinate funding from agencies that already fund telemetry to fund these kinds of studies, e.g. ONR and NMFS, and compile findings. MEDIUM

Follow-up workshop to review these studies. MEDIUM

Recommendations

Recommendations by the workshop participants were indicated under each specific section, but some are worth reiterating here:

- The potential risks to individuals from tagging must be weighed against the current risks to individuals and populations. Most workshop participants agreed that no tagging work should be carried out before a thorough evaluation of its justification and methodology.

- Tagging studies should first define the question or hypothesis to be addressed, then determine the methodology that will provide the answers with minimum impact on the population of interest. The benefits of tagging, in terms of knowledge gained, should be evaluated against the potential costs to both individuals and populations. The risk and stress to each tagged animal should be minimized and the tagging procedure should be carried out on no more individuals than is necessary to answer the question or test the hypothesis.

- Experience has shown that no two cetacean species react in the same way to particular capture or tagging procedures, so the assessment of any proposed study must be specific to the circumstances and species involved.

- Tagging efforts should always involve researchers and/or veterinarians with tagging experience.

- Tags and tagging should still be considered experimental. Substantial systematic research is needed to evaluate tag and attachment designs.

- A centralized database for tagging methods, materials, and success would be very useful and should be established and maintained. Researchers should keep records of tag mass, volume, footprint, and drag to relate to success.

- Consideration of dorsal fin anatomy led to several precautionary recommendations to: (1) minimize the involvement of major structural elements of the fin, (2) minimize damage to blood vessels by minimizing the number of attachment sites and using non-invasive imaging to locate blood vessels prior to penetration, or probing with a hypodermic needle to determine arterial positions, (3) study the species' anatomy in advance of tag design, and (4) allow flexibility into design of the tag and attachment system, to respond to blood vessel location variability (*e.g.*, multiple pin placement sites) (see appendix).

- Pins and pin placement should be designed such that once one linkage fails, the tag is immediately jettisoned.

- There is a strong need for research on active release mechanisms; this research should involve engineers with experience in marine environments who will be able to take into account variation in salinity, water temperature, and water flow.

- Most participants agreed that researchers have a strong ethical obligation to perform follow-up monitoring whenever possible, and to intervene as soon as possible if adverse impacts from tagging are indicated. The group recommended development of guidelines for determining when intervention is most important/appropriate. The central database (see above) should compile data from these cases. It was suggested that a federal contingency fund should be established for researchers to intervene if needed; typical research grants cannot cover these kinds of expenses.

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Appendix 1

DORSAL FIN MORPHOLOGY AND ATTACHMENT OF RADIOTAGS TO SMALL CETACEANS

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ABSTRACT

Recent advances in the development of radio tags and data loggers have provided field biologists with powerful new tools with which to study the biology of free-ranging cetaceans. For many species, however, advances in the methodology used to attach these tags have lagged behind electronic developments and it has proven difficult to attach tags for periods long enough to allow collection of meaningful data. This paper describes the efforts of several research groups to improve attachment methods for tagging small cetaceans. For most dolphins and porpoises, the dorsal fin has been the primary attachment site because it breaks the surface of the water when the animal breathes, a requisite for effective radio transmission at sea. We studied the anatomy of the dorsal fin of five species to map vasculature and to reduce the potential risks of tag attachment. We also conducted field studies of a variety of tag designs with eight species in diverse habitats, ranging from shallow, coastal bays to the open ocean. Together, these studies have allowed us to incorporate thermoregulatory and hydrodynamic factors into tag designs, improve the longevity of attachments from a few weeks to several months, and obtain more-detailed information about the lives of these animals in the wild. This paper provides guidance about the design of successful attachments, tradeoffs in the design and use of various attachments for different species and habitats, and a review of productive research approaches. In particular, we highlight the importance of collaboration and communication among diverse research groups in testing and developing new attachment designs.

Key words: cetacean, dolphin, porpoise, dorsal fin, morphology, vasculature, radio-tracking, tagging.

Introduction

Radiotelemetry and data loggers have become commonplace tools for studying marine mammals at sea. Their increasing popularity can be attributed to the development of smaller, smarter tags and to better attachment methods. These new technologies have greatly increased our understanding of the biology of free-ranging pinnipeds and manatees (*e.g.*, Kooyman 1965, 1989; Croxall *et al.* 1985; Gentry and Kooyman 1986; Mate *et al.* 1987; LeBoeuf *et al.* 1988; Rathbun *et al.* 1989; Bengtson and Stewart 1992; Reid *et al.* 1995; Deutsch *et al.* 1998). VHF radio tags have been used most often for coastal or short-term tracking and for studies in which observing detailed movements and behavior are important (Scott *et al*. 1990). Satellite tags have been used to track individuals for more than a few weeks, for studies offshore or other areas where accessibility is limited, and for studies of long-range movements (Mate 1989; Scott *et al*. 1990; Martin *et al.* 1993; Mate *et a*l. 1995; Dietz and Heide-Jørgensen 1995; Heide-Jørgensen and Dietz 1995; Wells *et al*. 1999a,b). Unfortunately, the widespread application of these tags and data loggers to the study of small cetaceans has been hindered by problems associated with attachment of tags to these streamlined, hairless and fast-swimming marine mammals (see previous reviews by Evans *et al.* 1972; Irvine *et al.* 1982; Scott *et al.* 1990; and Würsig *et al.* 1990).

In most previous studies of dolphins and porpoises, radio tags and data loggers have been placed on the dorsal fin because it provides a durable attachment site and allows the transmitter's antenna to clear the water's surface when the animal breathes. Transmitters and dataloggers have been mounted on saddles that wrapped around the leading edge of the dorsal fin (front-mounted design), on plates attached on one or both sides of the fin (side-mounted design), or on small tags attached along the trailing edge of the fin. Most dorsal-fin tags have been attached with bolts or pins (Scott *et al*. 1990), although suction cups have also been used to secure transmitters and data loggers for short periods (Goodyear 1993, Baird 1994, Schneider *et al*. 1998, Stone *et al.* 1998, Hooker and Baird 1999). Other methods have been used to tag cetaceans which lack a dorsal fin. For example, transmitters have been attached to the dorsal ridge of belugas (*Delphinapterus leucas*), narwhals (*Monodon monoceros*), and Amazon River dolphins (*Inia geoffrensis*) and even the tusks of narwhals (Martin and Smith 1992; Dietz and Heide-Jørgensen 1995; Martin and da Silva 1998).

This paper discusses recent advances in tag attachment methods and how these designs incorporated information about the potential harmful effects of tags, hydrodynamic drag, dorsal fin morphology and thermoregulation. Injuries to the dorsal fin were sometimes caused by the large radio tags used in the 1970s (Irvine *et al.* 1982) and the effects of tags on the dorsal fins of dolphins and porpoises were demonstrated by the pioneering studies by Bruce-Allen and Geraci (1985) and Geraci and Smith (1990). With the advent of smaller radio tags, the risk and severity of injuries were greatly reduced (Scott *et al.* 1990).

Hydrodynamic drag has been suggested to be a critical factor in tag design because excessive drag may hinder the animal's locomotion and increase metabolic costs (Evans 1971, Martin *et al*. 1971, Würsig 1982, Scott *et al*. 1990, Culik *et al*. 1994). Several front- and side-mounted tag designs described in this study were tested in a wind-tunnel and published by Hanson *et al*. 1998*a*. These tests indicated that, despite the fact that a front-mounted design tested had a relatively low cross-sectional frontal area, it had a similar amount of drag at typical dolphin swimming speeds (<5 kn or 10 km/h), and up to a third more drag near top swimming speeds than the side-mounted design.

The cetacean dorsal fin not only functions as a hydrodynamic control surface, but has a significant thermoregulatory role as well (see reviews by Slijper 1936, 1979; Pabst *et al.* 1999). Tags that disrupt the integrity of major blood vessels or that cover superficial veins may affect the animal's ability to thermoregulate, particularly the temperature of the reproductive organs (Scholander and Schevill 1955; Rommel *et al.* 1992, 1993, 1994). The first section of this paper describes the mapping of the major arteries and veins in the dorsal fins of several small odontocetes to determine whether the positions of these vessels could be predicted so that tags could be attached with minimal impact on fin vasculature. The second section describes several tag designs that were field tested in a variety of habitats by several research groups to provide information on tag longevity.

MORPHOLOGY OF DORSAL FINS

The cetacean dorsal fin is richly vascularized, being fed by intervertebral arteries and drained *via* two independent venous systems (Scholander and Schevill 1955, Elsner *et al.* 1974). The first is a deep, periarterial venous retia (PAVR) that surrounds and forms a counter-current heat exchanger (CCHE) with the nutritive arteries (Fig. 1). A second venous drainage system lies just below the epidermis and carries blood to the surface of the animal, where excess body heat can be transferred to the environment. These veins, and also the superficial veins of the flukes, supply a venous plexus deep within the abdomen. This lumbocaudal venous plexus is juxtaposed to the spermatic arteries in males and to the uterovarian arteries in females (Fig. 2). Thus, cooled blood is introduced into the abdomen in a position to regulate the temperature of the intra-abdominal testes and the developing fetus (Rommel *et al*. 1993, 1994; Pabst *et al.* 1995). Depending on the thermal needs of the animal, the dorsal fin can either conserve body heat *via* countercurrent exchange, or act as a “thermal window” to dissipate excess body heat.

Methods

The arteries of dorsal fins from two bottlenose dolphins (*Tursiops truncatus*) were injected with radio-opaque dye and radiographed. This technique visualized the entire branching patterns of deep arteries. Radiographs were recorded on videotape and drawn using EasyCad (Evolution Computing, Tempe, AZ) and a video superimposer (Precision Graphics Systems, Saco, ME).

Dorsal fins were also dissected from fresh carcasses of 5 bottlenose dolphins, 5 harbor porpoises (*Phocoena phocoena*), 3 shortfin pilot whales (*Globicephala macrorhynchus*), 1 Risso’s dolphin (*Grampus griseus*), and 1 pygmy sperm whale (*Kogia breviceps*). These animals had either stranded or had been captured incidentally in commercial fishing operations (Table 1). Each fin was placed onto a rectilinear graph and its outline traced. The fin was then sliced into 1-cm-thick frontal sections to expose major vessels (Fig. 3). Major vessels were defined as those greater than 0.5 mm in diameter, or an artery of any size surrounded by a PAVR that could be observed without magnification. The distance of each major vessel to the leading edge of the fin was measured to the nearest millimeter. The mean position of the cranial-most artery and mean inter-arterial distance for 12 fins were regressed against total body length (CricketGraph, Version 1.5.3 and SAS, Version 6). The pygmy sperm whale was not included in this analysis because it displayed some distinctive vascular patterns (described below) not shared by the other species.

The dorsal fins of five harbor porpoises were used to determine if the positions of the superficial veins were useful for predicting the positions of underlying arteries. A superficial vein and deep artery were considered "in register" if their linear positions were within 2 mm of each other (*i.e.*, within our measurement error of +/- 1 mm). We recorded for both the left and right side of the fin in each section the number of veins that were in register with underlying arteries and the number of arteries that were in register with an overlying vein.

Results

The general topography of arteries was similar in the species investigated (Fig. 4). Intervertebral arteries entered the dorsal fin at its base. Nutritive arteries in the cranial half of the fin coursed predominantly dorsally, while those in the caudal half of the fin swept dorsocaudally towards the fin's trailing edge. Each artery branched as it coursed distally through the fin. Associated PAVRs branched as well, and continued to surround each smaller arterial branch.

Across species, the mean inter-arterial distance was highly correlated with total body length (r^2 = 0.826; Fig. 5A). The distance from the leading edge of the fin to the position of the first artery was also correlated with total body length (r^2 = 0.750) and was approximately twice the mean inter-arterial distance (Table 1). Within species, though, where both the sample size and body size range were small, correlations between total body length and inter-arterial distance either did not exist (*e.g.*, harbor porpoise, r^2 = 0.0) or were weakly positive (bottlenose dolphin, r^2 = 0.625, pilot whale, r^2 = 0.538).

The base of the dorsal fin at the leading edge was typically devoid of large arteries (Fig. 6). This pattern was most pronounced in harbor porpoises and bottlenose dolphins; the distance to the first artery at the base was 2.55 and 1.56 times longer, respectively, than that distance at more distal positions along the height of the fin (column 5 *vs.* 7, Table 1). This pattern was not seen in the Risso's dolphin, however (Table 1).

Large arteries typically were not found along the leading edge of the dorsal fin. For most species, the distance from the fin's leading edge to the first artery was 1.5-2.4 times greater than the mean inter-arterial distance (column 6 *vs.* 7, Table 1). This pattern was not observed, however, in the Risso's dolphin or pygmy sperm whale. In the Risso's dolphin, the distance to the first artery was similar to the mean inter-arterial distance. In the pygmy sperm whale, arteries in the distal fin were very close to its leading edge (Fig. 6), sometimes to within 3 mm. The inter-arterial distance was also only 65% of that predicted by the scaling relationship for the other species (Table 1). As in other species, though, the arteries at the fin base were placed far from the fin's leading edge.

In harbor porpoises, 60% (range 42-75%) of superficial veins were in register with an underlying artery. Only 30% (range 16-45%) of all mid-line nutritive arteries were in register with an overlying superficial vein. Thus, the majority of arteries had no corresponding superficial veins marking their position.

Discussion

The goal of this morphological study was to provide quantitative data to minimize the effect of tag attachment on dorsal fin vasculature and, thus, thermoregulation. Ideally, such data would yield a "predictive map" of fin vasculature. A strongly predictive relationship does exist between inter-arterial distance and total body length across species, but individual variation within species renders this prediction useful only as a preliminary step in determining vessel location. The anatomical data do, however, illuminate the following general patterns of vascular topography.

(1) *Lack of major vessels at the base of the fin's leading edge*: The leading edge at the base of the fin typically lacked major vessels (Fig. 6). This feature, together with the thickness and robustness of this region, suggest that it is a good position to place pins for securing a tag.

(2) *Distance of the first artery from the fin's leading edge*: In the harbor porpoise, bottlenose dolphin, and pilot whale, the entire leading edge of the fin provides a region relatively devoid of major vessels. In the Risso's dolphin and pygmy sperm whale, the leading edge of the fin is well-vascularized (except at the fin base), and less suited for pin placement. Given these species differences, morphology studies of the fins of other species should be conducted to determine the suitability for pin placement along the leading edge.

(3) *Inter-arterial distance scales to body length*: Because the nutritive arteries of the dorsal fin are derived from intervertebral arteries, larger species with longer vertebrae will have larger inter-arterial distances. For example, the mean inter-arterial distance of pilot whales is about 2.5 times as great as that of harbor porpoises. Unfortunately, this scaling with body size is less predictive within a species due to individual variation. Thus, potential attachment sites should be tested for the presence of blood vessels before the pin is placed (see below).

***Thermoregulatory Concerns* -** The dorsal fin provides a large surface area for tag attachment, but it also acts as a "thermal window" across which excess body heat is dumped to the environment to achieve both reproductive and whole-body cooling (*e.g*., Scholander and Schevill 1955, Rommel *et al*. 1994, Pabst *et al.* 1995). Manipulating the surface temperature of the dorsal fin, which potentially could occur with coverage of the fin surface, has been demonstrated to affect deep body temperature in the region of the counter-current heat exchanger (Rommel *et al*. 1994). Therefore, one element of tag design should be to minimize coverage of the dorsal fin.

Damage to blood vessels within the dorsal fin may also compromise thermoregulatory function. Given the individual variation in vessel topography, we suggest that investigators attempt to determine exact vessel location before attaching the tag. Under captive situations, the use of non-invasive imaging techniques (*e.g*., diagnostic ultrasound) may be useful for determining the location of deep arteries. In the field, arteries can be avoided by probing potential attachment sites with a sterile, narrow-bore hypodermic needle before placing the pins. Superficial veins, which are visible upon external inspection of the fin, should be avoided. By providing the tag with several possible attachment points, researchers have the flexibility to avoid sites that are unsuitable.

The superficial veins in the dorsal fin supply cooled blood to the lumbocaudal venous plexus, which can cool, by counter-current heat exchange with reproductive arteries, the internal testes in males and the developing fetus in pregnant females. We are particularly concerned about any disruption of this cooling function in pregnant females, because any physiological or anatomical condition that limits the ability of the fetus to transfer heat to the mother can cause a potentially harmful increase in fetal temperature. Increases in fetal temperature are known to cause detrimental effects in terrestrial mammals, including low birth weights (Shelton 1964), retarded fetal growth (Alexander *et al.* 1987, Bell 1987), skeletal and neural developmental anomalies (reviewed in Lotgering *et al.* 1985), and ultimately acute fetal distress and death (Morishima *et al.* 1975, Cephalo and Hellegers 1978). Although these physiological factors would suggest caution in applying large tags to pregnant females, we have also observed bottlenose dolphins with severely damaged or missing dorsal fins have been known to give birth and successfully rear offspring in the wild (RW, MS, unpublished data).

TAGS AND ATTACHMENT TECHNIQUES

In designing a tag, one is confronted by a series of tradeoffs. One must balance the potential effects on thermoregulation, hydrodynamic drag, signal strength, tag longevity, package weight, vulnerability of the tag to physical damage, and the potential risk of injury to the animal. There is also an electronic tradeoff to be made between the signal strength, transmission rate, and range of a transmitter with its longevity. Having long-range tracking capability is particularly important for radiotracking pelagic or long-diving mobile species. Having a long transmitter life is important for answering questions about long-term behavior, seasonal residency, and migration.

Methods

Invasive tag attachments are medical procedures requiring aseptic techniques. Typically, the attachment site was cleaned with betadyne, the equipment and materials were sterilized, and the procedures conducted by trained and experienced personnel. A syringe needle was typically used to administer a local anesthetic (lidocaine hydrochloride) and to probe for blood vessels. If no significant blood vessels were found, a 5-mm hole was cored to accommodate a pin or a bolt. Ferric subsulfate solution was used when necessary to promote blood clotting.

The VHF radiotags used in these studies transmitted in the 148-150 MHz band. Plastic bolts or pins (typically Delrin) attached the packages through the dorsal fin and were secured with magnesium or steel nuts. Galvanic action between the metal nuts and adjacent washers made of dissimilar metals caused the nuts to corrode, allowing the tag to release after a certain amount of time. The inner edges of the tags were padded with neoprene or open-cell foam for cushioning.

Bikini tags - The "bikini tag" was designed for tracking pantropical spotted dolphins (*Stenella attenuata*) in the eastern tropical Pacific Ocean during 1992-1993. Because the tag was to be used in tropical waters, a small, two-piece saddle was designed to minimize coverage of the fin and potential effects on thermoregulation (Fig. 7, Table 2). Each piece was secured by a single Delrin plastic pin along the leading edge of the fin: one at the base of the fin and one about halfway up the fin. The semi-rigid antenna was sheathed in plastic tubing where it attached to the upper piece with a plastic cable tie; this protected the fin by dampening antenna vibrations and prevented the antenna from "fluttering" as the dolphin swam. The transmitters were adjusted to provide maximum range, relatively long signals, and a frequent transmission rate, all at the expense of longevity (Table 2). The range of the transmitter was approximately 24 km (13 nm) from large vessels with receiving antennas mounted 17-22 m above the waterline and more than 9 km (5 nm) from launches with 5-m-high antennas. A slightly larger package carried a time-depth recorder (TDR) as well. Silicon sealant was used as faring on the package to reduce drag.

Roto-radios - Nylon cattle ear tags, called "rototags," have been used frequently to identify dolphins for short periods (Norris and Pryor 1970, Irvine *et al.* 1982, Scott *et al.* 1990). Small epoxy-encapsulated VHF transmitters were bolted to the free ends of a rototag to provide a simple and relatively safe attachment method. "Roto-radios" attach easily with a single nylon pin and have been used primarily for short-term tracking of coastal cetaceans (Table 2). The rototag was clipped through the trailing edge of the dorsal fin after one starter hole had been made with a sterilized sharp instrument. The rototags could be attached only where the dorsal fin was thinner than 0.8 cm. To allow the attachment to thicker fins and to create a release mechanism, two female rototag halves were connected by a 0.64-cm-diameter threaded Delrin pin and secured by a magnesium nut.

Three different orientations of the transmitter and antenna were used. In one design, the transmitter was positioned horizontally, parallel to the longitudinal axis of the animal, with the front edge of the transmitter resting flush against the vertical trailing edge of the fin, thereby stabilizing the orientation of the transmitter parallel to the longitudinal axis of the dolphin's body (Fig. 8). The antenna was canted 45° above this axis. The horizontal orientation was designed to reduce drag, while the upward-canted antenna cleared the water at each surfacing and produced good signals. A second design had both the transmitter and antenna oriented horizontally to reduce drag further and possibly increase the longevity (Fig. 9). The third design had both the transmitter and antenna mounted vertically to increase the range.

Different transmitter models were used, depending on the tracking period and range required. One transmitter had an effective range of about 5 km (2 nm) from small boats and a nominal battery life of 2 weeks. We switched to a more-powerful transmitter, which had a range of 7-10 km (4-6 nm) by small boats and from at least 20 km (12 nm) from an aircraft and a battery life of 7 weeks.

Trac Pacs - The Trac Pac saddle can attach to the dorsal fin without pins or bolts. The vacuum-formed plastic saddle is usually custom-made for individual dolphins (Fig. 9). Non-skid latex bathtub mat material was glued to the inner surface of the saddle so that the mat's suction cups adhered to the fin. The saddle had external "pockets" to accommodate transmitters and TDRs with minimal drag. Chines (short, wing-like projections) were built on each side of the saddle so that the flow of water and resulting hydrodynamic pressure promoted adhesion of the saddle.

Magnesium linkages were incorporated into the leading edge of the saddle. When the linkages dissolved, the left and right halves of the saddle split apart and water pressure pushed the saddle off the fin. The whole package was positively buoyant. In some configurations, a Velcro strip wrapped around the rear edges of the saddle to keep the package together after it detached. Depending on the electronic equipment used, the package weighed 262-332 g. The Trac Pac has been extensively tested on captive and free-ranging bottlenose dolphins. These tests indicated that the magnesium linkages reliably jettisoned the packages.

Satellite-linked tags – Satellite-linked tags have been mounted on a variety of different packages (Table 2). Trac Pacs attached with Delrin pins have been used to track an Atlantic spotted dolphin, *Stenella frontalis* for 24 days (Davis *et al.* 1996), three Heaviside's dolphins (*Cephalorhynchus heavisidei*) for 50-116 days (FT, unpublished data), and a rough-toothed dolphin (*Steno bredanensis*) for 112 days (RW, unpublished data).

Two other types of platform transmitter terminals (PTTs) were developed and deployed on harbor porpoises, bottlenose dolphins, rough-toothed dolphins, and pantropical spotted dolphins (Table 2). To minimize the size of the PTT packages, only a single environmental sensor, a surface time counter, was employed. The cumulative time spent above the water surface was transmitted twice during each uplink, allowing detection of transmission errors. Each tag incorporated a salt-water switch, which conserved battery life by preventing transmission when the animal was submerged (although the switch does add another device that can fail or operate sub-optimally so that signals are lost, *e.g.*, Irvine *et al*. 1982, Hanson *et al*. 1998*b*). A duty cycle of six or eight h/day further conserved the batteries and provided several months of operating life.

The first type of PTT was a front-mounted design. The transmitter was encased in a stainless-steel cylinder initially attached with plastic tie-wraps to a thermoplastic saddle lined with 2.5-mm open-cell foam. This package was secured along the leading edge of the dorsal fin using three 8-mm high-density polyethylene (HDPE) and plated-steel lock nuts. Initial deployments (n=3) indicated weaknesses in this design. The HDPE pins sheared prematurely and the plastic tie wraps securing the tag to the saddle broke. Later deployments (n=2) with Delrin pins and stainless-steel hose clamps had improved retention times (20+ days).

The second type of PTT was a side-mount design (Fig. 10). The transmitter was encased in a molded Lexan housing that was mounted on one side of the dorsal fin. Three pins, two along the leading edge and one along the trailing edge, were secured with plated steel lock nuts (1/4") backed with Delrin washers (30 x 1.5 mm) on the opposite side of the fin. The tag was backed with 2.5-mm open-cell foam. Side-mounted tags have been successfully deployed on wild and rehabilitated harbor porpoises (Read and Westgate 1997, Westgate *et al*. 1998), bottlenose dolphins (Wells *et al.* 1998a), rough-toothed dolphins (Wells *et al.* 1998b), and pantropical spotted dolphins (AW; Melody Baran, Clearwater Marine Aquarium, personal communication). More recently, a modified version of the side-mount design was deployed which contained a satellite time-depth recorder that recorded diving behavior and transmitted these data through the Argos system for approximately six hours each day.

Releasable time-depth recorders - We have studied the diving behavior of harbor porpoises using two designs consisting of a TDR and a small VHF radio transmitter (Westgate *et al*. 1995, Westgate and Read 1998). The TDR/radio package was embedded in syntactic foam (Eccofloat EF-38A: Emerson and Cuming, Canton, MA) that made the package positively buoyant. In the first design, two nylon pins, embedded in the tag's epoxy housing, passed through Teflon-covered stainless steel tubes through the dorsal fin. The tubes were held in place with low-grade steel nuts backed with a neoprene-lined plastic washer. The tag itself was secured with small magnesium nuts that fit onto the protruding ends of the nylon pins. In the second iteration, the Delrin pins held the TDR onto the fin. The latter design eliminated the steel tubes which remained in the dorsal fin for an unknown period of time. It was difficult to predict the exact release time of the TDR, as it varied with the mass of the magnesium nuts and water temperature. Both tags were configured to float with the VHF antenna out of the water.

Results

The results of the field testing of the various tag designs consists of an evaluation of each tag.

Bikini tag - The bikini tag was designed to minimize potential negative effects on thermoregulation by reducing the area covered by the package and placing the pins in a thick, sparsely vascularized area of the dorsal fin. The drag value of this particular design was not determined, but another front-mounted design showed increased drag at higher swim speeds (Hanson *et al*. 1998*a*). While the streamlining needs to be improved, the advantages of the tag are its medium weight and size, and the stability of the antenna.

The transmitter had, by design, a short battery lifetime (about 2-3 weeks) to maximize range, so the potential longevity of the attachment could not be determined. No injuries due to tag attachment problems were observed when tags were removed from 5 dolphins after 1-4 days; one pin that would likely have migrated anteriorly however, had it not been removed, because it was located too close to the leading edge of the fin.

Roto-radio - The light weight and small size of the roto-radio, and the single attachment point on the trailing edge of the fin, minimize the risk of serious fin damage and potential thermoregulation problems. The orientation of the transmitter and the antenna affected the drag and the range of the transmitter. The horizontal transmitter and antenna configuration was thought to have the least drag, but the antenna tended to trail in the wake of the dorsal fin, weakening the strength of the signals. Having the antenna canted upward produced better signals and greater ranges. The vertical configuration appeared to cause additional drag (as revealed by a wake contrail and this increase in drag was deemed to outweigh any improvements in range, so this configuration was discontinued.

The attachment is short-term, with the longest track lasting 34 days (Read *et al.* 1996). Most of the tagged dolphins were resighted following loss of the transmitter. The tags left a hole or a notch along the trailing edge of the fin, but no other harmful effects were observed during or after tracking. These small notches have proved to be a useful feature, however, because they allowed re-identification of the dolphins after the tags were shed (Scott *et al*. 1990).

Trac Pac - The main advantages of the Trac Pac are its simple, non-invasive attachment, its custom-fit, streamlined design, and its reliable release mechanism. Using Trac Pacs, it is possible to deploy a variety of data loggers on free-ranging animals and recover the data without recapturing the animal. The major disadvantage is its relatively short attachment time. Trac Pacs have been modified for longer deployments by bolting them to the dorsal fin (see section on *Satellite-linked tags*).

Trac Pacs attached with suction cups do not present the potential risk of blood-vessel damage as more-invasive methods. The large amount of area of the dorsal fin covered by the package could possibly hinder thermoregulation, particularly for bolted-on packages required for longer-term attachments. The package is designed, however, to let water readily flow under the saddle to allow cooling. The package has a streamlined design, but the drag values of the saddle's wrap-around design needs to be determined. Suction-cup attachments lasted up to 14 hours. No harmful effects on the dolphins were observed; indeed, the suction-cup attachment avoided creating the holes required for securing packages with bolts or pins. Sometimes the dolphins shed the tag quickly by leaping or rolling, but otherwise little behavioral change in the dolphins due to the tags was observed.

Satellite-linked tags – The front-mounted configuration minimized the surface area of the fin covered by the tag to reduce potential thermoregulatory effects and was secured on the thickest part of the dorsal fin (approximately 2.5 cm from the leading edge) for stability and decreased risk of damaging blood vessels. The tag's mass was distributed evenly on either side of the dorsal fin to avoid differential drag on either side on the dorsal fin when the animal was swimming in a straight line. Wind-tunnel testing indicated, however, that drag was greater at higher swimming speeds than the side-mounted design (Hanson *et al.* 1998a). It was difficult to fit the tag precisely onto the fin, however, and the stainless-steel tubes contributed significantly to the total mass of the package. The periods of contact (up to 21 days) were shorter than expected, suggesting that the attachment longevity needed to be improved.

The side-mounted design covered more of the dorsal fin, but the open-cell backing foam should have allowed some water movement between the tag and the dorsal fin to allow cooling. The design also was not balanced but, like the front-mounted design, was attached to the thickest part of the fin. This configuration was much easier to fit and, at faster swimming speeds, was expected to create less hydrodynamic drag (Hanson *et al*. 1998a).

Periods of contact from 20 tags deployed on harbor porpoises have ranged from 26 to 212 days, but 4 tags on bottlenose dolphins only lasted between 37 and 43 days. These shorter periods of contact were likely due to the tags being dislodged. We have documented pin breakage on at least two occasions when the dolphins engaged in agonistic intra-specific encounters. Previous studies of bottlenose dolphins have suggested that the tags may also be damaged when dolphins rub or strike them on the bottom or on underwater objects (Irvine *et al*. 1982).

In three of the four deployments on bottlenose dolphins, we received only poor-quality location data (Service ARGOS classifies each location with an accuracy code: the fewer the number of uplinks per pass, the poorer the accuracy code; see, for example, Westgate *et al.* 1998). The transmitters were mounted near the base of the dorsal fin to reduce the risk that they would be knocked off during agonistic interactions, but in this position the transmitting antenna may be partially obscured by the dorsal fin and the few uplinks may have been caused by attenuation of the low-power (1/4-watt) signals by the dorsal fin. On the fourth dolphin the tag was mounted higher on the fin, which resulted in better-quality location data (Wells *et al.* 1999a). A similar deployment on two rough-toothed dolphins resulted in mostly good-quality location data and longevities of 4 and 112 days (RW, unpublished data). These two dolphins were resighted five months after their release; both had shed the satellite tags, but one still carried a roto-radio tag.

The side-mounted design had longer attachment times than the front-mounted design, perhaps due to less drag or better protection from battering by the animals. More care had to be exercised in placing the pins because of the central location on the fin, however, and in positioning the antenna to prevent possible attenuation of the signal by the dorsal fin.

Releasable time-depth recorders - We have recorded over 360 hours of diving data from harbor porpoises with these recoverable tags. The primary advantage to this design is that the animal need not be recaptured to recover the diving-history information from the dataloggers, although it requires the addition of a VHF radio to either follow the animals throughout the deployment or locate TDRs after they detach by tracking from airplanes or boats. The memory of the TDR can limit the amount of data collected, and the release mechanism also may fail or release the tag at unexpected times.

Discussion

The increase in the number and sophistication of telemetry studies has followed the evolution of smaller tags, more-reliable attachment methods, and improved TDRs. The longevity of tag attachments, previously limited to about three weeks (Irvine *et al.* 1982, Read and Gaskin 1985), has increased to several months. The incidence and severity of tissue damage that sometimes occurred in the 1970s when much larger tags were in use has been greatly reduced, although not completely eliminated. The ability to observe and recapture tagged dolphins and porpoises has allowed an assessment of the placement and attachment of tags and the effectiveness of tag components. These tagging studies have provided information on movement and activities, surfacing intervals and diving-depth histories, metabolic rates, acoustics, the fates of rehabilitated stranded animals, and the association of pelagic dolphins and tuna.

Tag Placement - Tag position is an important consideration relative to attachment duration. In studies in which both front- and side-mounted tags were deployed (Martin and da Silva 1998, Westgate and Read 1998), signals from side-mounted tags were generally received for substantially longer periods of time than from the front-mounted tags (Hanson 1998). Drag values for both designs were similar at typical swimming speeds, but the front-mount design resulted in greater drag at high speeds (Hanson *et al.* 1998*a*). It is possible that the side-mounted tags were less vulnerable to damage or removal by rubbing or interactions with conspecifics. The side-mount design may also have been less susceptible to excessive loading at the base of the leading edge of the dorsal fin, where substantial leverage could be exerted that could result in material fatigue and the premature failure of the device (Hanson 1998). Also, if the pins were to migrate, the retention time may be shorter for the front-mount design, because the pins are located near the forward edge of the fin. We still do not fully understand the relationship between attachment duration and drag, but we assume that a more hydrodynamic tag is more suitable for long-term deployments on marine animals. Comparable drag values of a number of these designs (particularly the front-mounted bikini tag and the wrap-around Trac Pac) still need to be determined.

Backing Materials - Neoprene or open-cell foam have been commonly used to pad the inner surface of tags designed for cetaceans. After recapturing spotted dolphins to recover TDRs, we found that the neoprene had been compressed to one-half or less of its original thickness, presumably as a result of pressure exerted during dives as deep as 200 m. This compression can potentially loosen the fit of the package. Open-cell foam has the advantages of not losing its loft after sustained periods at depth, and also allows some water to percolate between the tag and the fin. Backing materials should be tested at the depths to which the study animal is suspected to dive. The effects of different backing materials on water flow over the dorsal fin and on thermoregulation have yet to be examined.

Release Mechanisms - Typically, tags are designed to release from the dorsal fin, ideally at the end of the tag's expected working life. The performances of magnesium linkages used as release mechanisms for tags have become more precise, although we have found that extensive calibration is required for each tag design. The corrosion times of other links (such as high-carbon-steel nuts and stainless-steel washer combinations) should be tested. Better release mechanisms should be incorporated into tag design so that an animal will not be burdened with the tag for any longer than is necessary (*i.e*., the life of the batteries). More active release mechanisms are being tested as well. A line cutter that is activated by radio signal sent by the researchers to release tags is being used on large whales (S. Chivers, personal communication). Similarly, an acoustically triggered release mechanism has been tested on harbor seals, *Phoca vitulina* (Hammill *et al*. 1999).

Pins and Bolts - There are several factors to consider when selecting the number and kinds of pins or bolts to secure a tag to a dorsal fin. More pins provide more stability, but with an increased risk of damaging the vasculature of the dorsal fin. Too few pins, however, may not provide enough support for the tag and make migration through the fin more likely (Irvine *et al*. 1982). Typically, 1-5 pins have been used to secure radio tags, depending on the size of the package, the size and blood vessel locations of the dorsal fin, and the amount of abuse the package is expected to undergo.

Pin size is also important, and this can affect both the longevity of the attachment and any potential damage to the dorsal fin. If too small a pin is used, it will have more tendency to break or migrate out of the tissue (more force on less tissue area) and if too large a pin is used, it will be more likely to impact a major blood vessel. For the side-mounted PTTs, we typically use 6.4-mm pins for smaller cetaceans such as harbor porpoises, and 7.9-mm pins on larger animals such as bottlenose dolphins.

Early radiotagging studies discovered that packages secured with stainless-steel bolts could cause damage to the dorsal fin (Irvine *et al*. 1982). More recently, Delrin or nylon have been commonly used as pin materials because they are strong and have good biocompatibility. Delrin has proved to be more brittle than nylon, which means it will shear when subjected to sufficient force. This could be advantageous if one is tagging small animals which are at risk of getting their tags caught in debris or fishing gear. One bottlenose dolphin carried a satellite tag secured with five Delrin pins for 25 days (Mate *et al.* 1995). The dolphin was recognized 3.5 months later from a photograph that showed her freezebrand and faint dark dots where the pin holes had been. The pins had presumably sheared and released the package, rather than migrating through the dorsal fin, and healing was complete.

No matter what type of bolt or pin is used, an important consideration is the tightness of the fastening nuts, which can be difficult to gauge. There was a tendency during some initial tag attachments to over-tighten the nuts securing the packages. During examinations of these recaptured dolphins, indentations, and, in some cases, necrosis on the dorsal fin could be detected when the package had been fitted too snugly. The amount of water flow under the tag may also be related to tightness of the nuts. Intuitively, one would expect that over-tightened nuts would restrict water flow and potentially create thermoregulation problems, but this has not been tested in the field.

Antennas - Rigid antennas were used in early tracking studies (Evans 1971, Irvine *et al.* 1982, Norris *et al*. 1994), but more-flexible antennas were used after it was observed that rigid antennas were susceptible to breaking (Irvine *et al*. 1982, Norris *et al*. 1994, Hanson *et al*. 1998b). Flexible antennas may also reduce the drag and the risk of injuries during social interactions with conspecifics. Rigid antennas were used on the bikini tags to gain antenna height and range while tracking spotted dolphins in the open ocean, where it would be unlikely that the animal could break the antenna on the seafloor. In a study of Hawaiian spotted dolphins, a higher antenna also made the seawater switch more effective (J. Jennings, personal communication).

CONCLUSIONS

Experience has shown us that each species and field situation presents unique challenges to field biologists interested in using telemetry to study small cetaceans. Seldom is there an ‘off the shelf’ solution to a particular problem. Instead, field biologists with knowledge and experience of a particular species should work with engineers, programmers, and functional morphologists to obtain an optimal solution for each application.

We have found that an iterative approach is the most efficient way to develop effective tags and attachments. The incorporation of small, successive changes have proven more successful than trying to effect many major changes quickly, because it is possible to learn from sequential trials. Implicit in this approach is the idea that it may require many test deployments before real success is achieved, as measured by the duration of the deployment and reliability. As an example, the harbor porpoise satellite telemetry study evolved over three field seasons of gradual design changes before we were able to develop a safe, effective attachment design. This iterative approach requires the ability to monitor the condition of the animal and tag in the field. For satellite tags, monitoring in the field can be difficult unless the package also contains a VHF transmitter. We recommend simultaneous tracking with radio and satellite tags so animals can be relocated to identify specific problems after release, and so that the data obtained from the satellite tag can be ground-truthed. When using this approach, it is preferable that the VHF and satellite radios be attached independently so that the animals can still be tracked if one attachment fails.

Opportunities to test tag and attachment designs on wild dolphins and porpoises are limited. The ability to test various designs on captive animals in a non-invasive manner would be of great benefit. To date, there have been few such opportunities (although see Kastelein *et al*. 1997), but tagging coastal animals with restricted home ranges has resulted in many resightings to monitor tag performance and longevity. Trained captive dolphins and porpoises can provide a unique opportunity to examine the effects of added drag caused by tags. Such studies have been conducted on aquatic birds, such as penguins (*e.g*., Culik *et al*. 1994) and should also be conducted on small cetaceans.

Live stranded dolphins and porpoises provide one of very few opportunities to study poorly known species (*e.g.*, pilot whale: Mate 1989; Atlantic spotted dolphin: Davis *et al*. 1996; harbor porpoise: Westgate *et al*. 1998; offshore bottlenose dolphin: Wells *et al*. 1999a; rough-toothed dolphin: RW, unpublished data; pygmy sperm whale: Scott *et al.* 2001). Because such studies are opportunistic, there is often little time to apply for funding or prepare for tracking in the field. We have had to scramble at such times to order or borrow gear, design and fabricate attachment saddles, arrange for tracking vessels or satellite time, and fit the tags to the animals before releasing them. It would be desirable for the agencies that manage these species to maintain an inventory of radio tags, satellite tags, and TDRs, and funds to deploy them on rehabilitated animals that are returned to the wild.

Radiotelemetry of cetaceans is still the province of a relatively small number of biologists with a keen appreciation for fine electrical tape and a high tolerance for monotonous beeping in the wee hours of the morning. This paper is a result of continuing collaborative research among field biologists and functional morphologists. Sometimes, tags were designed by one group of field biologists and anatomists, tested in a laboratory by a different group, and then tested and refined in the field by yet another group. Many of the advances (and deadends) in this field have been a result of such collaborations. Exchange of experiences about our failures has been particularly important because it is difficult to publish papers devoted to unsuccessful tag designs. We believe that it is important, particularly for novice radio trackers, to become part of such a network so that innovative ideas can be rapidly tested and so that unsuccessful designs need not be reinvented.

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Table 1. Data generated from dorsal fins of five species of odontocete cetaceans (Total Length measurements in centimeters, all other measurements in millimeters). Columns include: First Artery at Base, the distance from the leading edge of the first dorsal fin serial section to the first major artery with a surrounding venous return (PAVR); First Artery-Mean, the mean of the first PAVR from all serial sections of each dorsal fin; Interarterial- Mean, the mean of the interarterial distance for all arteries from all serial sections of the fin.

Species	**Field Number**	**Sex**	**Total Length**	**First Artery At Base**	**First Arterial Mean**	**Interarterial Mean**
P. phocoena	NMFS 00265	M	119	43	19.7	8.8
P. phocoena	NMFS 00256	F	142	59	19.8	11.7
P. phocoena	NMFS 0026	M	122	14	12.0	9.3
P. phocoena	NMFS00465	M	138	28	12.7	8.5
P. phocoena	NMFS 00140	M	163	31	18.7	9.0
T. truncatus	---	M	---	53	27.5	15.9
T. truncatus	VMSM 931028	M	163	25	20.2	13.0
T. truncatus	VMSM 941089	M	206	36	25.6	13.0
T. truncatus	VMSM 941101	M	265	35	25.4	15.5
T. truncatus	VMSM 941093	M	208	54	34.3	15.0
G. griseus	VMSM 951001	M	172	28	28.2	31.0
K. breviceps	GA 91071001	F	288	41	13.0	23.7
G. macrorhynchus	VMSM 941008	F	339	70	43.8	21.2
G. macrorhynchus	VMSM 941005	F	372	48	54.9	27.3
G. macrorhynchus	VMSM 941004	F	349	68	66.0	27.3

Table 2. Tracking studies of cetaceans.

Tag Type	Species/Area	N	Transmitter	Package	Attachment
"Bikini" tag	*S. attenuata* ETP	4	MOD-050-HP[1]	Front mount (105 g); expanded-PVC plastic	6.4-mm Delrin pins (2) magnesium nuts
"Bikini" tag with TDR	*S. attenuata* ETP	7	Mk 5 TDR[2]; MOD-050-HP[1]	Front mount (180 g); expanded-PVC plastic	6.4-mm Delrin pins (2) magnesium nuts
Rotoradio	*T. truncatus* Sarasota, FL (Waples, 1995)	5	Model F1018[3]	Jumbo Roto Tag[4] (18 g); horizontal transmitter, antenna canted 45º	Nylon rototag pin (1)
	T. truncatus	1	Model F1018[3]	Jumbo Roto Tag[4] (18 g); horizontal transmitter, antenna canted 45º	6.4-mm Delrin pin (1) magnesium nut
	S. clymene Gulf coast FL	1	Model F1018[3] horizontal transmitter,	Jumbo Roto Tag[4] (18 g); antenna canted 45º	Nylon rototag pin (1)
	T. truncatus Beaufort, NC	9	Model F1018[3] 5.5 x 2.5 x 1.1 cm	Jumbo Roto Tag[4] (15 g); horizontal transmitter and antenna	Nylon rototag pin (1)

	P. phocoena Bay of Fundy	9	Model F1018[3]	Jumbo Roto Tag[4] (15 g); horizontal transmitter and antenna	Nylon rototag pin (1)
	L. acutus Gulf of Maine	2	Model F1018[3]	Jumbo Roto Tag[4] (15 g); horizontal transmitter and antenna	Nylon rototag pin (1)
	S. bredanensis E. Gulf of Mexico	1	Model F1018[3] horizontal transmitter,	Jumbo Roto Tag[4] (18 g); antenna canted 45º	Nylon rototag pin (1)
Trac Pac	*T. truncatus* Sarasota, FL Beaufort NC	10	Model F1018[3]	Trac Pac plastic saddle (262-332 g)	Bathmat suction cups
	S. frontalis Texas (Davis *et al*. 1996)	1	Model SLTDR[2] Model 050[1]	Trac Pac plastic saddle (625 g)	6.4-mm Delrin pins (3)
	C. heavisidei South Africa	3	Model SDR-T6[2]	Trac Pac plastic saddle	6.4-mm Delrin pins (2-3)
	S. bredanensis E. Gulf of Mexico	1	Model ST-10[1]	Trac Pac plastic saddle	8.0-mm Delrin pins (4) steel nut/brass washer
Satellite tag					
	P. phocoena Bay of Fundy (Read and Westgate, 1997)	3	Model ST-10[1]	Front mount (265 g) thermoplastic saddle	8.0-mm HDPE pins (3) plated-steel locknuts
	P. phocoena Bay of Fundy	2	Model ST-10[1]	Front mount (265 g) thermoplastic saddle	8.0-mm Delrin pins (3) plated-steel locknuts
	P. phocoena Bay of Fundy	20	Model ST-10[1]	Side mount (150 g) Lexan backing plate	6.4-mm Delrin pins (3) plated-steel locknuts and Delrin washers
	P. phocoena Bay of Fundy	4	Model SDR[2]	Side mount (175 g) Lexan backing plate	8.0-mm Delrin pins (3) plated-steel locknuts
	T. truncatus Gulf of Mexico	4	Model ST-10[1]	Side mount (175 g) thermoplastic saddle	8.0-mm Delrin pins (3) plated-steel locknuts

	S. bredanensis Gulf of Mexico	2	Model ST-10[1]	Side mount (175 g) thermoplastic saddle	8.0-mm Delrin pins (3) plated-steel locknuts
	S. frontalis NW-Atlantic	2	Model ST-10[1]	Side mount (175 g) thermoplastic saddle	8.0-mm Delrin pins (3) plated-steel locknuts
Releasable TDR	*P. phocoena* Bay of Fundy	8	Model Mk 5 TDR[2] Model AI-2sp[5]	Side mount (120 g) epoxy tag/plastic backing washer/syntactic foam for bouyancy	6.4-mm nylon pins (2) Teflon-covered steel tubes, magnesium and low-grade steel nuts
	P. phocoena Bay of Fundy	2	Model Mk 5 TDR[2] Model AI-2sp[5]	Side mount (120 g) epoxy tag/plastic backing washer/syntactic foam for bouyancy	6.4-mm Delrin pins (2) magnesium and low-grade steel nuts

[1]Telonics, Mesa AZ
[2]Wildlife Computers, Woodinville WA
[3]Advanced Telemetry Systems, Isanti, MN
[4]Dalton Supplies, Nettlebed, England
[5]Holohil Systems, Woodlawn, Ontario

Figure 1. Arterial and venous circulation of the dorsal fin in a bottlenose dolphin, *Tursiops truncatus*. **A.** Outline of a bottlenose dolphin; horizontal line marks the position of the cross-section illustrated in D. **B.** Arterial supply to the dorsal fin is derived from intervertebral arteries. **C.** Venous drainage of cooled blood from the surface of the dorsal fin. Blood routed through these veins will enter the abdominal countercurrent heat exchanger (CCHE). At the dorsal border of the oblique abdominal muscles, these veins dive deep to supply CCHE. **D.** Cross-section of the dorsal fin at level identified in A. Circulation consists of deep arteries surrounded by a periarterial venous rete (PAVR), and laterally placed superficial veins.

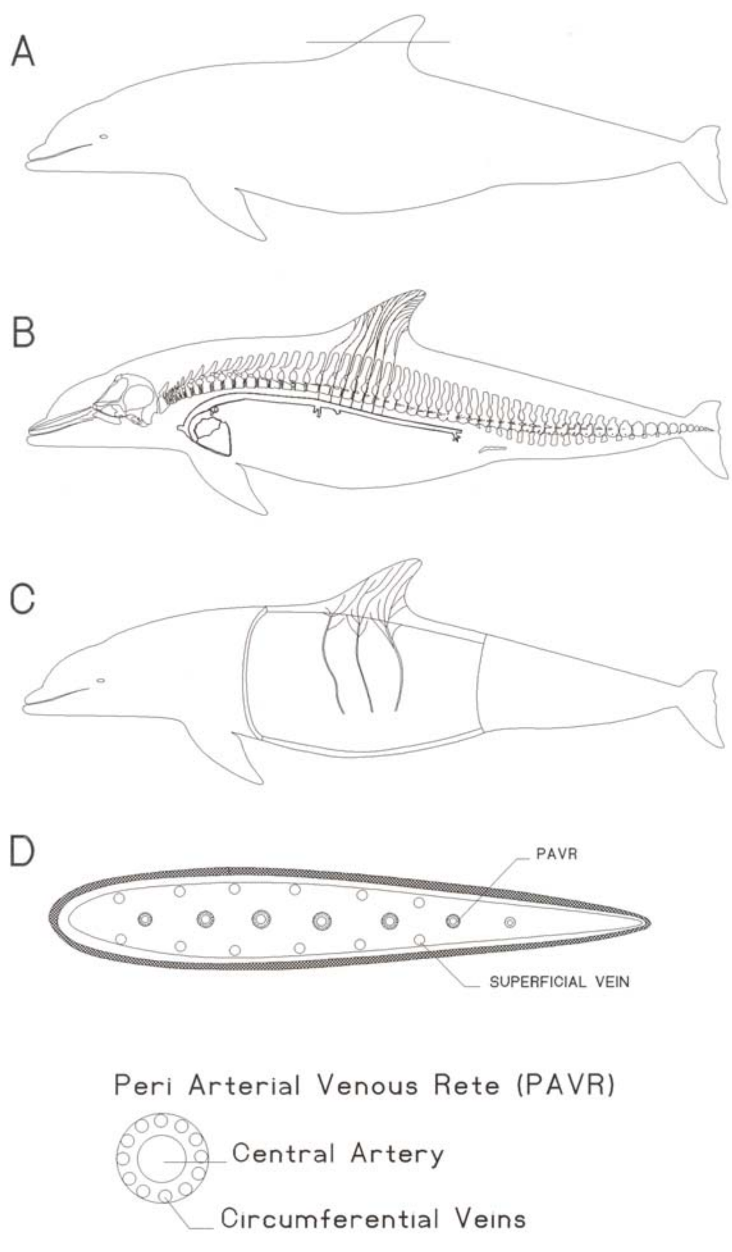

Figure 2. Schematic representation of the vascular structures that form the counter-current heat exchanger (CCHE) of a dolphin. **A.** Venous circulation that supplies the CCHE with cooled blood from the dorsal fin and arterial plexus that arises from the dorsal aorta and supplies the testis. **B.** Cross-section of the caudal abdominal cavity illustrating the testes surrounded by thermogenic muscle and insulative blubber. **C.** Oblique left lateral view of the CCHE. The arteries and veins are organized into single layers that are oriented roughly parallel to each other. This arrangement allows for the transfer of heat from the nutritive arteries to the cooled venous blood returning from the dorsal fin and flukes.

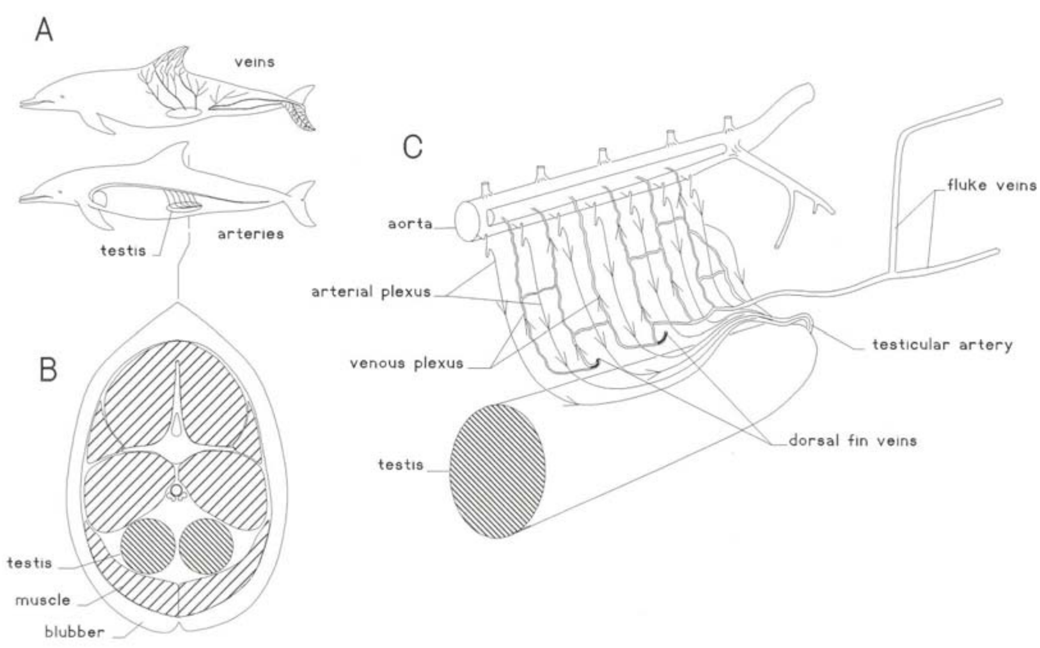

Figure 3. Dorsal fin of a bottlenose dolphin, *Tursiops truncatus,* illustrating 1-cm serial sections cut through the fin. In addition, it illustrates the technique of stacking individual sections and maintaining each section in register (see Fig. 4b). The bottom panel illustrates an individual cross-section that has been rotated to show the measurement of a deep artery, surrounded by a PAVR, and a superficial vein.

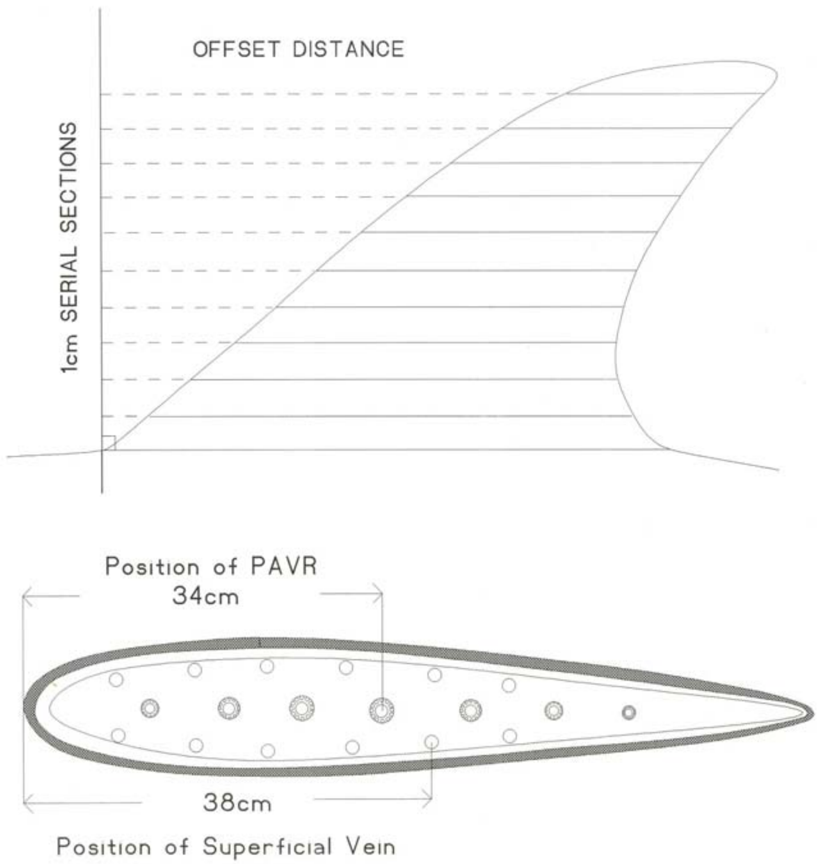

Figure 4. Vascular topography of dorsal fin of a bottlenose dolphin, *Tursiops truncatus*. CAD drawing of a radiograph of the dorsal fin; only deep arteries and surrounding PAVRs are illustrated here.

A

B

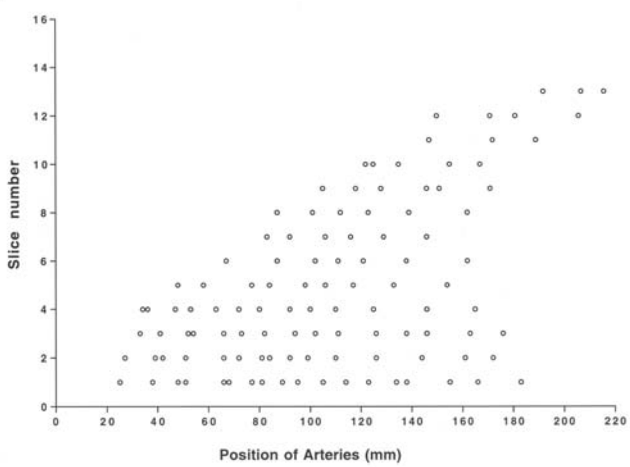

Figure 5. Arterial distances scaled to body length. **A.** Total length of all species used in this study (except pygmy sperm whale, *Kogia breviceps*) graphed against the mean inter-arterial distance within the dorsal fin. **B.** Total body length graphed against the distance from the leading edge of the dorsal fin to the first artery in each serial section.

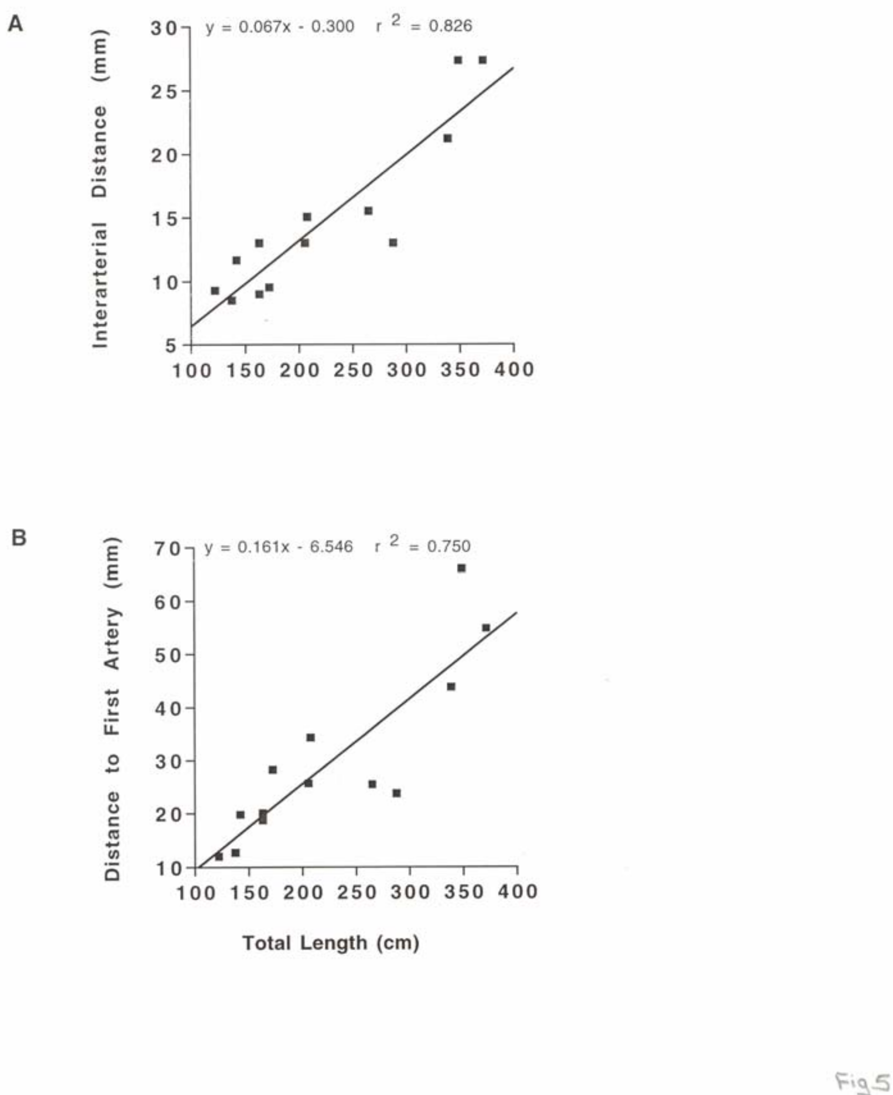

Figure 6. Position of cranial-most arteries throughout the height of the fin in: **A**. harbor porpoise, *Phocoena phocoena*, **B**. shortfin pilot whale, *Globicephala macrorhynchus*, **C**. bottlenose dolphin, *Tursiops truncatus*, and **D**. pygmy sperm whale, *Kogia breviceps*. Notice that at the base of the fin, the cranial-most artery is set far caudally relative to the more distal positions along the height of the fin. Dotted vertical line represents the mean inter-arterial distance for each individual.

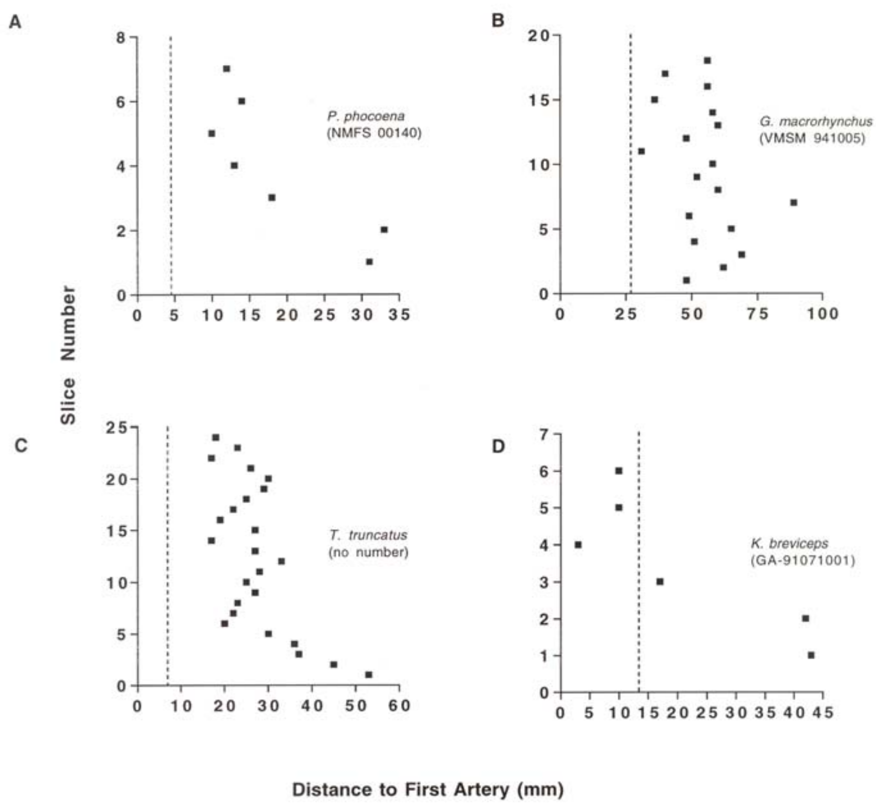

Figure 7. Bikini tags deployed on spotted dolphins (*Stenella attenuata*) in the eastern tropical Pacific Ocean. Front-mounted VHF transmitter is secured to the two-part saddle with plastic cable ties. The saddles are secured with delrin pins and the square magnesium nuts pictured here.

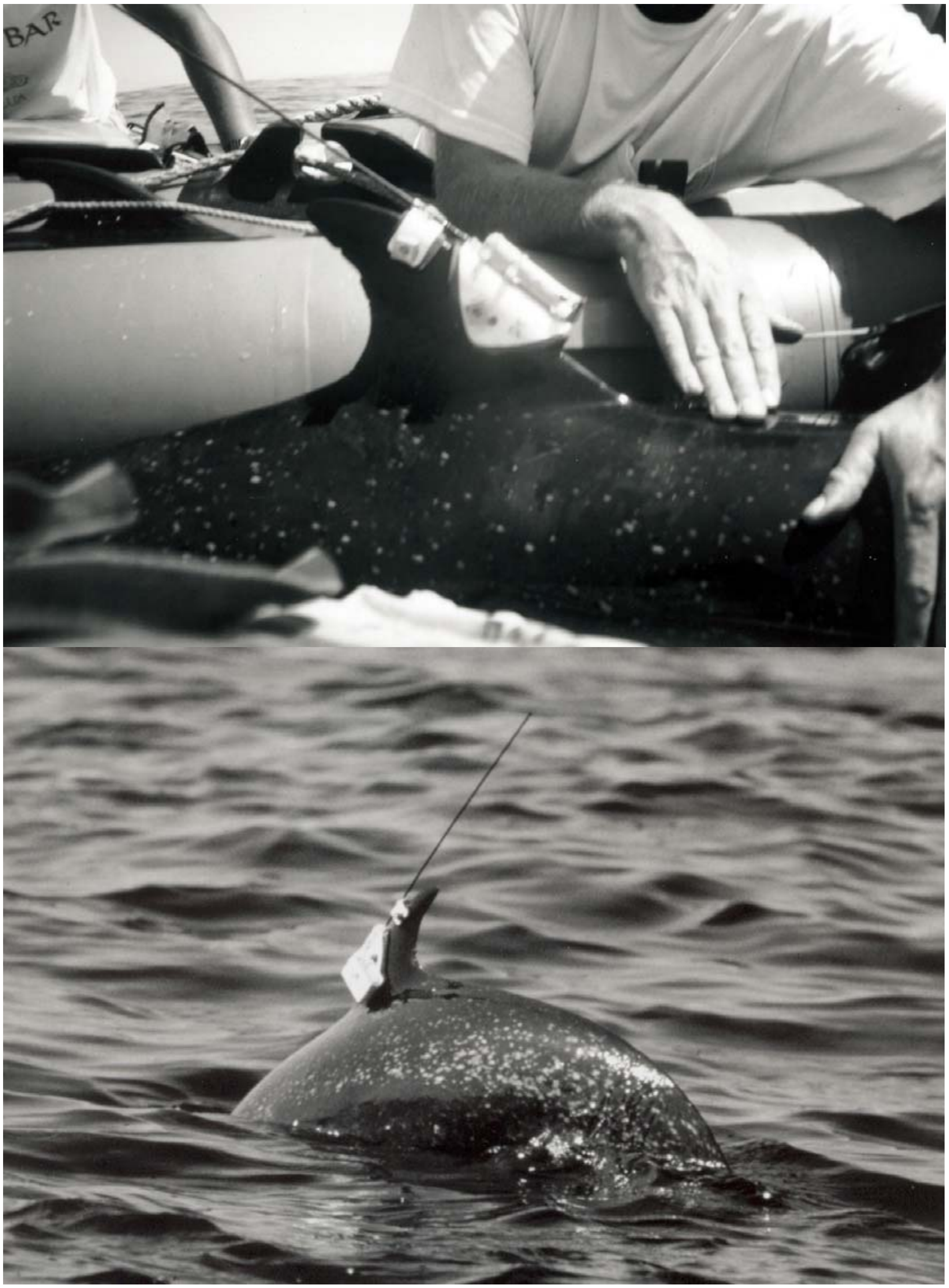

Figure 8. Roto-radio and Trac Pac deployed on a bottlenose dolphin (*Tursiops truncatus*) in Sarasota Bay, Florida. The roto-radio is mounted on the top, trailing edge of the fin; the VHF transmitter and antenna are oriented horizontally. The Trac Pac is attached to the fin with suction cups and secured with a Velcro strap wrapped around the rear of the fin. The package is released when the two magnesium linkages at the front of the package dissolve. A vertically oriented VHF transmitter allows short-term tracking of the dolphin and then recovery of the package once it falls off the fin (the buoyant saddle is weighted to allow the antenna to break the surface of the water after release). A horizontally oriented data logger records water temperature, depth and time. A data logger on the other side of the package records the skin temperature and heat flux of the dorsal fin.

Figure 9. Side-mounted PTT deployed on a harbor porpoise (*Phocoena phocoena*) in the Bay of Fundy. The backing plate is attached to the dorsal fin with three Delrin pins and secured with plated steel nuts backed with washers on the opposite side.

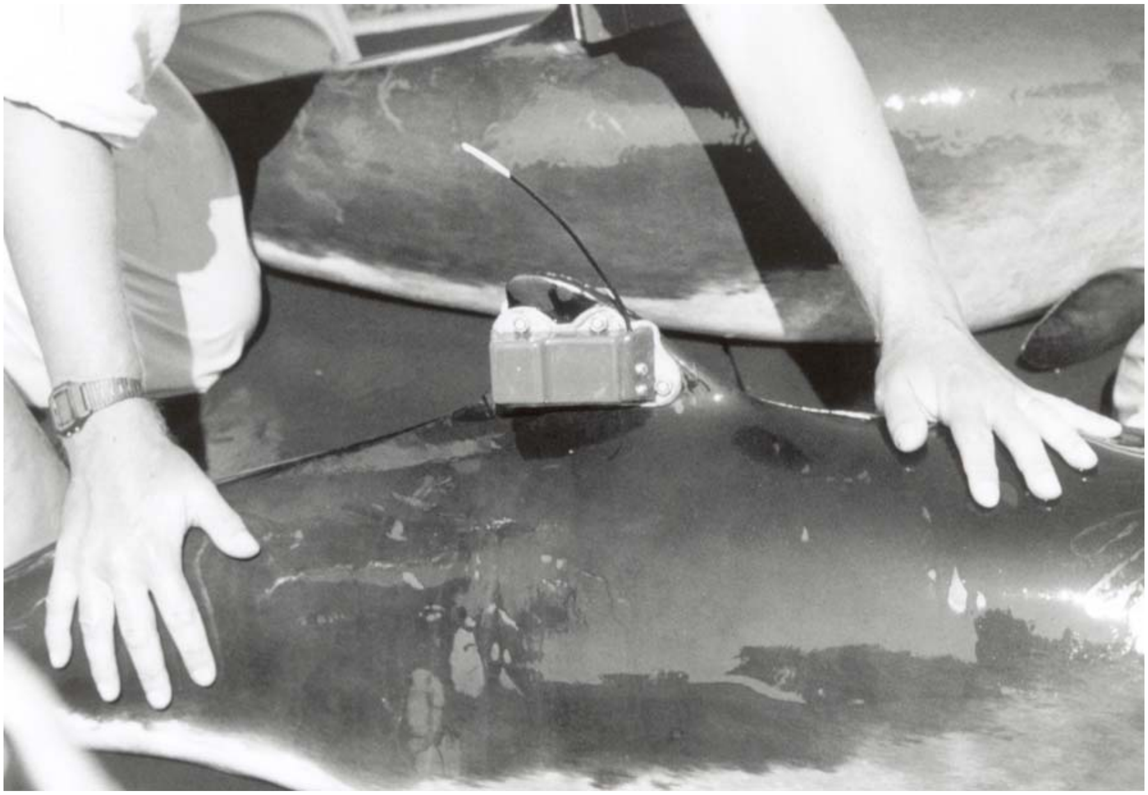

Figure 10. Releasable TDR deployed on a harbor porpoise (*Phocoena phocoena*) in the Bay of Fundy. A vertically oriented transmitter and a TDR are encased in syntactic foam. The package is attached with Delrin pins and secured with low-grade steel nuts on one side and dissolving magnesium nuts on the other.

Appendix 2

THE FUNCTIONAL VASCULAR ANATOMY OF THE CETACEAN DORSAL FIN

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The cetacean dorsal fin, which functions both as a hydrodynamic and thermoregulatory control surface, is a richly vascularized appendage (reviewed in Slijper 1936, 1979; Pabst *et al.* 1999). The fin is fed by intervertebral arteries and drained *via* two independent venous systems (Scholander and Schevill 1955, Elsner *et al.* 1974). The first is a deep, periarterial venous retia (PAVR) that surrounds and forms a heat conserving, countercurrent heat exchanger (CCHE) with the nutritive arteries. A second venous drainage system lies just deep to the epidermis and carries blood to the surface of the animal where excess body heat can be transferred to the environment. Thus, depending on the thermal needs of the animal, the dorsal fin can either function to conserve body heat *via* countercurrent exchange, or act as a "thermal window" across which heat is lost to the environment.

The superficial veins that drain the dorsal fin carry cooled venous blood that can be used to achieve whole body cooling (Scholander and Schevill 1955) and to regulate the temperature of internal reproductive tissues (Rommel *et al.* 1992, Rommel *et al.* 1993). These veins, as well as the superficial veins of the flukes, supply a venous plexus deep within the abdomen; the lumbocaudal venous plexus is juxtaposed with the spermatic arteries in males and with the uterovarian arteries in females. Thus, cooled blood is introduced into the abdomen in a position to regulate the temperature of the intra-abdominal testes (Rommel *et al*. 1994, Pabst *et al.* 1995) and the developing fetus (Rommel *et al*. 1993).

The dorsal fin, which contributes to both whole body as well as reproductive thermoregulation, is also used by researchers as a site of attachment for satellite and radio tags. Many current tag designs require placing holes through the fin, and some tags require covering a considerable surface area of the fin. Any manipulation of the fin that disrupts the integrity of major vessels and/or that covers superficial veins would affect the animal's ability to thermoregulate (Rommel *et al*. 1994). Although the extent of this effect is presently unknown, a tag that minimizes interaction with the vascular structures of the dorsal fin would be preferable.

The purpose of our study was to acquire quantitative data on the vascular structures of the cetacean dorsal fin; such data could enhance an investigator's ability to design a minimal impact dorsal fin tag. Dorsal fins were collected from fresh carcasses of *Tursiops truncatus* (n=5), *Phocoena phocoena* (n=5), *Globicephala macrorhynchus* (n=3), *Grampus griseus* (n=1), and *Kogia breviceps* (n=1) that had either stranded or been incidentally caught in commercial fishing operations. Each fin was sliced into 1 cm thick serial sections in the frontal body plane to expose major deep and superficial vessels. The position of each major vessel was measured (to the nearest mm) from the leading edge of the fin section. Mean position of the cranial-most artery and mean inter-arterial distance for each fin were regressed against total body length for those specimens where total length was known.

Our results suggest that the general topography of nutritive arteries was similar in all species investigated. Intervertebral arteries enter the dorsal fin at its base. Nutritive arteries in the cranial half of the fin course predominantly dorsally, while those in the caudal half of the fin sweep dorsocaudally towards the fin's trailing edge. Each artery branches as it course distally through the fin. Associated PAVRs branch as well and continue to surround each smaller, distal branching artery.

Across species, the mean inter-arterial distance is highly correlated to total body length (r^2=0.909). The distance from the leading edge of the fin to the position of the first artery is also correlated to total body length (r^2 = 0.841) and is approximately twice the mean inter-arterial distance. Within species, though, where both the sample size and size range are small, correlations between total body length and inter-arterial distance either do not exist (e.g. *P. phocoena*, r^2 = 0.0) or are weakly positive (*T. truncatus*, r^2= 0.625, *G. macrorhynchus*, r^2= 0.538). In most species investigated, the leading edge at the base of the dorsal fin appears to be devoid of large arteries. In *P. phocoena* and *T. truncatus* this effect is most pronounced; the distance to the first artery in the base is 2.55 and 1.56 times longer, respectively, than that distance at more distal positions along the height of the fin.

The vasculature within the dorsal fin of *K. breviceps* differs from that of the other species investigated in two ways. The small inter-arterial distance seen in *K. breviceps* is only 65% of that predicted by the scaling relationship for the other species. In addition, the cranial-most arteries in the distal fin are very close to its leading edge. As in other species, though, at the fin base the cranial-most arteries are placed far from the fin's leading edge.

Thus, although a strongly predictive relationship does exist between inter-arterial distance and total body length across species, individual variation within species renders this prediction useful only as a preliminary step in determining fin vessel placement. The anatomical data do, though, illuminate the following general patterns of vascular topography that suggest useful strategies for tag design.

(1) *Lack of major vessels at the base of the fin's leading edge*: In all species investigated, the leading edge base was devoid of major vessels. This feature, together with the mechanical robustness of this region of the fin, suggests it as an advantageous position for placing pins to secure the tag.

(2) *Distance of the first artery from the fin's leading edge*: In most species, the distance from the fin's leading edge to the first artery, along the height of the fin, was greater than the mean inter-arterial distance. Thus, the entire leading edge of the fin provides a region for pin placement relatively devoid of major vessels. As a cautionary note, however, this pattern was not observed in *K. breviceps*.

(3) *Inter-arterial distance scales to body length*: Because the nutritive arteries of the dorsal fin are derived from intervertebral arteries, larger species with longer vertebrae will have larger inter-arterial distances. For example, the mean inter-arterial distance of *G. macrorhynchus* is about 2.5 times greater than that of *P. phocoena*. Unfortunately, a 140 cm long *P. phocoena* may have a mean inter-arterial distance of 13 mm or 20 mm. Thus, individual variation in vascular topography requires probing for exact vessel placement on any individual to determine the best sites for pin placement (see below).

Minimizing Fin Coverage and Number of Securing Pins

The lateral surfaces of the fin obviously provide the largest area for tag attachment, but these surfaces also act as "thermal windows" across which excess body heat is dumped to the environment to achieve both reproductive and whole body cooling (e.g. Scholander and Schevill 1955, Rommel *et al*. 1994, Pabst *et al.* 1995). Manipulating the surface temperature of the dorsal fin, which could occur with any coverage of the fin surface, has been demonstrated to effect deep body temperature in the region of the CCHE (Rommel *et al*. 1994). Therefore, dorsal fin tags should be designed to minimize fin coverage.

Likewise, destruction of vessels within the dorsal fin will compromise thermoregulatory function and designs that minimize the number of pins used to secure the tag would be advantageous. Given the individual variation in vessel topography we suggest that investigators attempt to assess exact vessel placement before attaching the tag. Under captive situations, the use of non-invasive imaging techniques (*e.g*. diagnostic ultrasound) should be investigated as a method to mark the location of deep arteries. In the field, probing the fin with a narrow-bore hypodermic needle may be a useful technique to test a potential site for arteries before attaching pins. All attempts should be made to avoid superficial veins, which visible upon external fin inspection.

Initial tag design should begin with knowledge of the fin anatomy of the target species. Once the overall shape and placement strategy for the tag is determined, an adaptive response can be "designed in" by having multiple pin attachment sites available within the body of the tag. Given that researchers cannot have prior knowledge of *exact* vessel placement for individuals captured in the wild, such flexibility would provide for subtle adjustments required to minimize impact on a given individual.

Who Should be Tagged?

The superficial veins in the dorsal fin supply cooled venous blood to the CCHE, which functions to cool the internal testes in males and the developing fetus in pregnant females. We are particularly concerned about any disruption of CCHE function in pregnant females, because any physiological or anatomical condition that limits the ability of the fetus to transfer heat to the maternal environment can cause a potentially harmful increase in fetal temperature. Increases in fetal temperature are known to cause detrimental effects including low birth weights (Shelton, 1964), retarded fetal growth (Alexander *et al.*, 1987; Bell, 1987), skeletal and neural developmental anomalies (reviewed in Lotgering *et al.*, 1985), and ultimately acute fetal distress and death (Morishima *et al.*, 1975; Cephalo and Hellegers, 1978). Because Rommel *et al.* (1994) have demonstrated that manipulation of the fin can cause increases in deep body temperatures, we strongly urge against tagging any pregnant female. Given the difficulty in assessing reproductive status of wild cetaceans under most field conditions, and given the long time periods that tags might be attached, we suggest that only males and obviously sexually immature females are targeted for long-term tagging.

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Appendix 3

SUMMARY OF TAG ATTACHMENTS USED ON *STENELLA* SPP. IN THE EASTERN TROPICAL PACIFIC OCEAN

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Tags were used in studies of pantropical spotted dolphins (*Stenella attenuata*) and eastern spinner dolphins (*S. longirostris orientalis*) on three research cruises in the eastern tropical Pacific. Each cruise had a common research objective, which was to track dolphins for a short period of time using VHF radio tags. The first two field studies took place in 1992 and 1993 and were specifically designed to investigate the tuna-dolphin bond by simultaneously tracking pantropical spotted dolphins and yellowfin tuna (*Thunnus albacares*). The third field study took place in 2001 and was designed to investigate physiological responses of individual dolphins chased and encircled during purse-seine fishing activities. Dolphins were tagged and tracked in this experiment to facilitate re-capture and re-sampling of the tagged individual's herd mates. Again, the primary study species was the pantropical spotted dolphin.

During the 1992 and 1993 research cruises, we tagged 11 pantropical spotted dolphins. We mounted VHF radio tags on a front-mount saddle with a 'bikini' top. The saddle was made of closed cell foam and was similar to the saddle design we used in 2001 (see Figure 2 #1 in Chivers and Scott 2002) except that the front of the saddle was solid. The 'bikini' top was also made of closed cell foam and was used to stabilize the tag package. Each saddle was lined with neoprene. Seven (7) of the 11 telemetry packages deployed included a time-depth data logger (TDR; Wildlife Computers, Model Mk5). The VHF radio tags and TDRs were attached to the saddles using cable ties. The saddle used to deploy these tags was slightly enlarged on one side to accommodate the TDR. Each telemetry package was attached to the dorsal fin using two ¼-inch delrin pins that were secured with magnesium nuts. The tracks lasted from 3 hours to more than 4 days. Five (5) of the 7 telemetry packages deployed with TDRs were recovered, and the entire package was removed from the dolphin. The first package removed in 1992 revealed evidence of pressure necrosis around the attachment holes in the dorsal fin. Subsequent deployments of the tag packages were not as tight and pressure necrosis was not obvious when the telemetry package was removed. No migration of attachment pins was noted but enlargement of one hole caused by a pin placed too close to the leading edge of the dorsal fin was noted. The longest track recorded was 103 hours (or 4.3 days), and no evidence of pressure necrosis or pin migration was noted when the TDR telemetry package was recovered from that individual.

During the 2001 field study, which was known as the Chase Encirclement Stress Studies (CHESS) cruise, 9 pantropical spotted dolphins were radio tagged and tracked and 6 spotted dolphins were satellite tagged and tracked. One dolphin was selected from each set as the focal individual to be tracked, and each dolphin carried a VHF radio tag and a data logger, which was either a time-depth recorder (TDRs; Wildlife Computers Model Mk 7) (n=3), a time-depth-velocity recorder (TDVRs; Wildlife Computers Model Mk 8) (n=4) or time-depth-velocity-heat flux recorder (aka a "thermal" tag, which is described in Pabst *et al*. 2002) (n=2). We recovered 2 TDRs, 2 TDVRs and both thermal tags. Dolphins were tracked from 1 to 6 days. Satellite tagged dolphins were tracked from 2 to 20 days. One additional TDR/VHF radio tag was deployed on an eastern spinner dolphin (*Stenella longirostris orientalis*) but was not tracked. We also attached 213 visual tags (all spotted dolphin) and 8 short-range radio tags (1 spinner and 7 spotted dolphins) to obtain information about dolphin associations in the herds that we captured.

The radio tag and data logger that comprised each telemetry package were held in molded pockets on a molded plastic saddle (Trac Pac, Fort Walton Beach, FL). The saddle was padded on the inside with a bilayer of 2-mm Blue Poron and 2-mm Blue Puff, which is the same type of padding used to reduce skin irritation in human prosthetic devices. The shape of the molded pockets held each component in place without cable ties, glue or epoxy. Saddles were attached to the dorsal fin with two or three ¼-inch (0.64-cm) Delrin pins. The Delrin pins were secured by magnesium nuts that corroded in sea water. The nuts were square and about ¼-inch thick to facilitate rapid corrosion so that the package would come off in a few days or weeks. The various configurations of the saddle used are depicted in Fig. 2 of Chivers and Scott (2002).

The short-range VHF radio transmitter put on some dolphins caught in association with the focal dolphins were attached through a single hole in the trailing edge of the dorsal fin. We used pins from the AgriTag visual tags (see below) to attach the transmitter, after cutting away the tag flaps.

Two models of satellite tags were deployed on spotted dolphins: one reported geolocation and depth (Model SDR-T16, Mold 87, Wildlife Computers, Woodinville, WA) and the other one reported geolocation data only (ModelSPOT2, Mold 126, Wildlife Computers, Woodinville, WA). These tags were mounted on one side of the dorsal fin with only plastic washers covering the other side of the fin. The tags and washers were lined same padding used to line the telemetry package saddles: a bilayer of 2-mm Blue Poron and 2-mm Blue Puff. Three ¼-inch (0.64-cm) delrin pins were used to attach the tag to the dorsal fin, and the pins were secured with stainless steel washers to facilitate long-term attachment of these tags.

Other dolphins in the herd were visually tagged ("rototagged", Scott *et al*. 1990) for later identification with either AgriTag (sheep/goat model with an antibacterial coating on the pins, AgriLaboratories, St. Joseph, MO) or Jumbo roto tags (Dalton, Nettlebed, England) (Fig. 2 in Chivers and Scott 2002).

Short-term tag attachment problems were not observed with the more-rigid plastic saddles used in 1992 and 1993, with the exception of one pin that had been positioned too close to the leading edge of the fin. The more-flexible plastic saddles used in 2001 better conformed to the fin and were more hydrodynamic, but more care and experience was required to avoid over tightening the nuts that could cause short-term pressure necrosis. No evidence of pin migration or enlargement of the attachment site holes was noted. In addition to the flexibility of the plastic used to make the saddles in 2001, the padding in these saddles was resilient to the pressure experienced at depths of >100m, whereas the neoprene used in 1992 and 1993 compressed to about ½ its thickness when the dolphins dove to depth, and thus likely provided extra space for compression/expansion of the saddle with changes in depth.

During each cruise, dolphins were administered a local anesthetic before a telemetry package was attached. Multiple injections were made near each attachment site. In 1992 and 1993, we used lidocaine, but in 2001, we used 4% prilocaine HCl (brand name is Citanest, manufactured by Astra Zeneca, which was available to us and is considered a substitute for carbocaine or lidocaine). All of the equipment used, including the delrin pins, was thoroughly cleaned with the final step being a rinse in an anti-bacterial solution (In 2001, we used Cetylcide II from Cetylcide Industries, Pennsauken, NJ, which is a broad spectrum disinfectant and hospital cleaner with germicidal, fungicidal and virucidal properties). We kept the delrin pins in a solution of Cetylcide until they were used to keep them as clean as possible in the field.

The focus on re-capturing dolphins during the 2001 cruise afforded us a unique opportunity to collect blood samples from nearly all dolphins that carried telemetry packages. For many of these dolphins we were able to get blood when the packages were attached and removed. Field determinations of white blood cell counts (WBC) indicated an increase between the time of the initial and final blood sample, which was taken after 1 to 2 days of tracking. Initial WBCs (all are reported in units of 10^3cells/mm^3) averaged 9.8 (range: 6.0-12.9, n=6), which was close to the average for all dolphins sampled when first captured during this project [average WBCs = 10.0 (range: 5.95-18.6, n=50); St. Aubin 2002). Although WBCs were observed to be higher for re-sampled dolphins not carrying telemetry tag packages when re-captured 3 days later: 12.05 (range: 9.7-15.4, n=3), two dolphins re-captured 1 and 2 days after being outfitted with a 'bullet' tag and a roto tag (one individual with each tag type) showed no change in WBCs. The increase in WBCs observed for individuals carrying telemetry packages was greater and averaged 18.5 (range: 11.9-28.8, n=4). The changes in individual WBCs after carrying telemetry tag packages ranged from 0.5 to 5.8, and many of these dolphins were also noted to have acute inflammatory responses evident at the tag attachment sites (see page 11, last paragraph in St. Aubin 2002). These are preliminary results suggesting a fairly immediate, acute response to the surgical procedures of tag attachment. Additional data for a suite of blood constituents are also available, and detailed analyses of the blood data is needed to better interpret the nature of the acute response indicated by the increased WBCs as well as the variability in individual responses to tagging procedures.

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Appendix 4

Tagging of Belugas, Narwhals, Botos, and Tucuxis

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Belugas (Delphinapterus leucas)

Handling. Belugas are normally captured in shallow water and, after release from the net, restrained with a rope around the peduncle. The loop of the rope is covered with rubber hose to avoid skin abrasion. The rope is normally attached to shore during the attachment process, so the whale faces the sea. Air and water temperatures are low, and there may be wavelets breaking over the dorsal ridge, even when the animal is backed up on the sloping beach as far as possible. Animals are maintained in water throughout, and typically released after a handling period of 20 mins. Capture myopathy is rare (c.1% in my experience), and belugas are apparently very tolerant of capture and handling procedures. Only sub-adults and adults were handled.

Attachment. Early work by Sergeant and Brodie involved the use of ‘spaghetti’ tags attached via a pole from a small boat. More recent deployment of VHF and satellite-linked tags have overwhelmingly used nylon pins placed through the tissue of the dorsal ridge, terminated by nylon nuts welded into position after careful tightening. My work (collaboratively with teams led by Tom Smith, Pierre Richard and Christian Lydersen) has consistently involved boring a 6mm hole through the ridge from side to side, and using 6mm nylon rod to hold in place a saddle of 3mm thick conveyor belting on which the tag is placed. The cores do not penetrate the fascia between blubber and muscle, and bleeding is minimal. We were advised by vets not to use local anaesthetics, and to inject antibiotics only when they have a dual purpose (as in Tetracycline for marking teeth). Indeed, we do notice that whales react more to the intramuscular antibiotic injection than to the 6mm blubber core. Pins and corers are routinely kept as sterile as possible, but in practise it is impossible to maintain a sterile field, especially if seawater is breaking over the attachment site.

Beluga blubber is thick and flexible, and their bodies flex considerably. Tag attachment must take account of this, which is why saddles (or, more recently, braided attachment wires) are themselves flexible. Flexible pins are much preferred over rigid ones for the same reason.

The tissue forming the dorsal ridge is mostly exceptionally weak in physical structure, and only the 3mm dermis holds pins in place. We assume that the pins migrate out of the ridge, allowing the transmitter to be lost.

This author has only used a non-surgical attachment technique for one batch of transmitters – at the request of town authorities in Churchill, Manitoba, who were reluctant to give consent for so-called 'invasive' techniques. Consequently, a thoracic harness was devised, to which the transmitter was attached. These harnesses provoked the most intensely negative reaction that I have seen in more than 600 tagging events, and I would never consider using such devices again. They are FAR more invasive, in the true sense of the word, than any pinning techniques I have seen. The Churchill authorities wisely gave consent to surgical attachments in subsequent years.

Few belugas have been closely observed more than a few days post-deployment. Orr et al. (1998) report on three, and in each case the site of transmitter attachment had healed, leaving barely discernable lines showing the path of pin movement. Typical transmitter life, which probably reflects attachment time, is 3-6 months.

Narwhals (*Monodon monoceros*)

Capture techniques usually (though not always) involve work in deeper water than is normal for belugas, but subsequently the animals are restrained and tagged in much the same way. Two differences are that narwhals have even less of a dorsal ridge than do belugas, and of course that older males have a uniquely convenient transmitter attachment substrate emerging from their upper jaw. Hose clamps can provide an excellent attachment to the tusk, though its rotation during growth may cause the transmitter's antenna to be rotated to a downward (and thereby more often submerged) position during longer-duration radio transmitter deployments.

Botos (*Inia geoffrensis*)

Handling. In a project I co-lead with Vera da Silva within the Mamirauá Reserve, Brazil, Amazon river dolphins are captured by seining them on to a sandy shallowly shelving beach. They are then immediately transferred to a stretcher on a small boat, and subsequently laid out on a foam mattress on the large, covered raft which acts as our laboratory. All age- and reproductive-classes of animals are handled, although the more vulnerable (calves < 6 months and heavily pregnant females) are processed particularly quickly. Handling times are typically 4-7 min (neonates) to 20 min. Stress most often presents as a withholding of breath; in extreme cases (<1%) dolphins arch their backs and the blowhole becomes flaccid. We have experienced one death in approximately 500 captures, so this must be considered a species robust to capture and handling. Air temperatures are high (25^o-33^o), and botos are kept moist to help prevent overheating.

Attachment. We use cored 6mm holes in the dorsal ridge, and 6mm nylon rod terminated by welded nylon nuts, to attach both plastic Allflex cattle tags (1 pin) and VHF/UHF radio transmitters (3 or 4 pins). Earlier transmitters were wrap-around style, but subsequent experimentation showed that side-mounted devices (15mm washer and nut on the other side) provided greater longevity (6-12 months typical, 15 months max) and left nothing but a small hole in the fin which quickly healed over when the transmitter fell away (Martin and da Silva, 1998). Little or no pin migration was seen in these deployments when animals were recaptured one or more years later and closely examined. Four animals retained a single pin which appeared, on inspection, to likely be permanently held in place. In these, skin had apparently formed on the inside of the bored hole, thereby isolating the implant. About half of the wrap-around devices left permanent notches on the ridge. In extreme cases these can look unsightly to our eyes, though similar damage is commonplace from intra-specific fighting and none has been seen to disadvantage a boto in either short- or long-term.

All equipment coming into contact with botos is sterilised as far as possible, though lapses certainly occur. It is interesting to me that the many open wounds of botos seem very rarely to become infected, despite them living in warm fresh water full of all kinds of biotic agents. They clearly have a powerful immune system, and this may help explain why we have never observed any infection from the hundreds of surgical procedures we have carried out on this species.

Botos have extraordinarily flexible bodies, and the dorsal ridge is no exception. I am confident that any device that 'fought' such flexibility (*e.g.*, with rigid pins) would result in more tissue damage and shorter duration attachments.

Tucuxis (*Sotalia fluviatilis*)

We have handled six tucuxis, and quickly confirmed their reputation for being easily stressed, as are we when handling them! They are similar to bottlenose dolphins in shape and tissue type, but we have not yet attached anything more than a small 'Rototag' cattle ear tag to the tip of the dorsal fin in the interests of minimising contact time. Three of the six animals showed clear signs of capture myopathy within 5 min of capture and were immediately returned to the water where they recovered instantly. The other three were released without problems after less than 10 min. No tags are known to have remained on tucuxis for more than 3 months, though freeze brands can be effective for years.

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Appendix 5

SATELLITE TAGGING AND POTENTIAL EFFECTS ON HARBOUR PORPOISES (*PHOCOENA PHOCOENA*) IN NORTH SEA AND BALTIC WATERS

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Introduction

During the past decade, satellite telemetry has shed light on the movements, behaviour and population structure of cetaceans, information that was previously impossible to collect. Due to the relatively large size of the early generations of transmitters, the tagging of most small cetacean species has been limited until recent years, when the transmitters have become smaller in size and weight.

Many kinds of tags have been used in studies of cetaceans, including VHF transmitters, satellite tags and dataloggers. Small cetaceans have been followed for longer periods by VHF or satellite tags, *e.g*., belugas (*Delphinapterus leucas*), 30-126 days (Richard *et al.*, 2001); 14-104 days (Suydam *et al.,* 2001); 5-177 days (Heide-Jørgensen *et al*., 2003a), Dall's porpoise 2-378 days (Hanson 2001), harbour porpoises (*Phocoena phocoena*), 2-212 days (Read and Westgate, 1997); 50 days (Westgate *et al*., 1998); 6-349 days (Teilmann *et al*., 2003); narwhals (*Monodon monoceros*), 22-100 days (Dietz and Heide-Jørgensen 1995), 6-145 days; Dietz *et al.*, 2001; 13-421 days (Heide-Jørgensen *et al.*, 2003b) and pilot whales (*Globicephala melas*) up to 47 days (Bloch *et al.*, 2003).

For long term attachment, transmitters are mounted to the front or the side of the dorsal fin or the dorsal ridge with two to four nylon, delrin, stainless steel or titanium pins (4-9mm diameter) (*e.g.*; Read and Westgate, 1997; Richard *et al.*, 2001). In the case of male narwhals the tags can be secured around the tusk of the animals by use of stainless steel hose clamps (Dietz *et al.*, 2001). Only few studies have evaluated the effect of tags on the behaviour and physiology of the animals. The reason for this limited number of studies is the logistical difficulty associated with following and observing wild cetaceans for long periods of time, both before and after attachment of transmitters. Generally only small changes in behaviour have been observed (Martin and Smith, 1992; Read and Westgate 1997; Otani *et al.* 1998). Only for bottlenose dolphins have more thorough studies have been conducted on the effects of radio tags and visual identification tags (Irvine *et al*. 1981; Scott *et al.* 1990). Generally these tags on bottlenose dolphins only stayed on for a limited period and the tissue never seemed to heal around the foreign objects probably due to water drag from the rather large early generation tags.

Population structure and movements of harbour porpoises in the North Sea and adjacent waters has been subject to great interest in recent years due to the high level of bycatch in gillnet fishery and little knowledge of the effect on populations. This paper reports on the major results obtained during the satellite tagging study on harbour porpoises conducted in the period 1997-2003 in Danish waters. In addition, a summary of the first systematic record on behaviour of a captive cetacean equipped with both a satellite and a VHF radio transmitter is provided.

Methods

Transmitters deployed

During 1997-2003, satellite transmitters were mounted on 54 harbour porpoises. Six different types of Argos satellite transmitters were used (Table 1, Figure 1). All tags were mounted with three 5mm delrin pins to the dorsal fin either on the frontal edge of the fin or to one side of the fin with a backing plate of conveyor belt material lined with soft neoprene on the other side.

Table 1. List of types and numbers of satellite transmitters mounted on harbour porpoises from 1997 to 2003 in Danish waters

Transmitter type	**Number of porpoises tagged**
Telonics ST-10	3
Telonics ST-18	6
Sirtrack Kiwi 101	7
Wildlife Computers SPOT2	10
Wildlife Computers SDR-T10	15
Wildlife Computers SDR-T16	13
Total	**54**

Tagging procedure

The harbour porpoises were live by-caught by fishermen in pound nets in Danish waters. The scientists were contacted by the fishermen and the tagging was conducted the same or the consecutive day. When taken onboard the animals were given a physical examination to decide whether it was suitable for tagging. Heart rate was measured and blood samples taken on most animals (Fig. 2). In addition to these procedures, twenty of the porpoises were freeze branded with liquid nitrogen (7 cm bronze numbers applied for 10 sec.) to mark the animals for future resightings (Fig. 2).

Study of a captive animal

A captive harbour porpoise from Harderwijk Dolphinarium was monitored for 80 consecutive days: 10 days before attachment of a satellite dive recorder and a VHF-radio tag, 30 days during deployment, and 40 days after removal of the transmitters. Dive data recorded by the satellite transmitter were collected during the deployment period. Daily food intake was measured and each week the porpoise was taken out of the water for a physical examination.

Results
In total 21 porpoises were tagged in the Skagerrak/North Sea region while 33 porpoises were tagged in the Kattegat and Danish Belts. The animals were tracked for up to 349 days (mean =101 days).

Table 2. Sex and age class distribution of harbour porpoises tagged in Danish waters from 1997 to 2003.

Tagged animals			
Females		Males	
Adults	Subadults	Adults	Subadults
6	16	10	22

During the breeding season there was no overlap in the home ranges of adult porpoises tagged in the two areas, respectively. We suggest a population boundary in the northern Kattegat across the Danish island of Læsø (see proposed boundary in Fig. 3). This population structure is supported by genetic studies (Teilmann *et al*., 2003). Seasonal migration between the Inner Danish Waters and the North Sea was observed in one case; a subadult female tagged in the fall swam about 600 km and overwintered in the North Sea and returned to the tagging area in the consecutive spring. Another porpoise tagged in Skagerrak over-wintered west of the Shetland Islands. The porpoises tagged in the Skagerrak preferred the southern Skaggerak and northeastern North Sea along the deep trench along Norway. In Kattegat and the Danish Belts the porpoises preferred the narrow straits where upwelling occurs and high fish concentrations are reported. Home range analysis revealed that none of the harbour porpoise habitats pointed out by Denmark under EU Habitat Directive was of particular interest to the tagged animals.

Study of a captive animal
The study of a rehabilitated harbour porpoise gave interesting results on the reaction to the satellite tags prior to release into the wild. Behavioural observations logged on a handheld computer showed an immediate effect of the tagging in time spent resting at the surface (logging), which was four to six fold higher on the day of attachment (Geertsen *et al*. accepted). Digital video recordings showed a significant increase in the mean duration of rolls at the surface immediately after attachment. The mean duration of dives was shorter before attachment than both after the tagging and after removal of the transmitters. Furthermore the frequency of surfacings farthest away from where the porpoise was taken out of the pool for tagging, was highest the first five days following the tagging. The heart rate was fairly constant during the tagging, but the mean heart rate increased significantly from 161 beats per minute (bpm) to 180 bpm after the first hole in the dorsal fin was made (Fig. 4).

The body weight of the porpoise increased up to the time of tagging (16 May 2000), after which it decreased until six days prior to release (28 July 2000). This was likely due to the seasonal trend in blubber thickness in harbour porpoises rather than an effect from the tagging. After one month of attachment, a skin reaction occurred around the frontal pinhole and the transmitters were removed. This reaction was probably due to drag from two tags and seaweed attached to the tags during the last part of the attachment period. After the tags were removed epithelia closed the pinholes after two days (Geertsen *et al.* in press).

Discussion

This study has proven successful in following individuals for up to a year and elucidating seasonal movements, critical habitats and stock structure essential in the management of harbour porpoises in the eastern Atlantic.

Observations of the captive tagged porpoise revealed new information on the behavioural and physiological effects of tag attachment. However, it also showed a strong need to further study tagged animals in captivity, especially to find ways of attachment that improve healing of the pin holes in the dorsal fin.

Harbour porpoises are generally very nervous animals that often become very stressed when taken out of the water. However, no animals have died during the tagging procedure in this study, except for one severely injured animal, that died shortly after it was taken out of the water. We believe that if a carefully planned procedure is applied, and the animals' heart rates are continuously observed, harbour porpoises can be safely handled and tagged.

Considerations and recommendations when satellite tagging small cetaceans

1) Collect relevant information on target animal (previous experience on catching, handling, tagging and behaviour).

2) Define objective and decide on appropriate method to meet your objective.

3) Conduct relevant experiments on captive animals.

4) Decide candidates and time for tagging (before field work) e.g.:
- Minimum/maximum size
- Females or males
- Condition (blubber thickness, reflexes, appearance, etc.)
- Sensitive season (breeding or feeding season)

5) Get experience on catching and handling elsewhere before tagging.

6) Establish procedure and brief the team before tagging.

7) Documentation is very important
- Log sheet of animal data and procedures supplemented with pictures is essential
- Video recordings of procedure and breathings in combination with heart rate is helpful in effort to reduce stress during subsequent handling.

8) Porpoises are easily stressed. Reduce stress by:

- Let the animal adapt to the captive situation in the water before taking it onboard.

- Place animal on a soft and stable mattress to reduce pressure on lungs and animal movements.

- Cover body in wet towels to avoid overheating and drying skin.

- Water frequently over head to stimulate breathing.

- Lower body in water after >1 min apnea to reestablish stable breathing.

9) Heart rate is a good measure of stress.

- Harbour porpoises should immediately be lowered back into the water when heart rate < 50 bpm or > 200 bpm until stable breathing is reestablished.

10) Keep control of the situation

- Everybody should know what to do

- Keep quiet, move slowly and work calmly through the procedure

- Be ready to act quickly

- *Debrief and evaluate how to improve next time*

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Fig. 1. Blood sampling, heart rate measuring, video recordings of breathing, handling and behaviour, freeze branding and satellite tag deployment of a harbour porpoise.

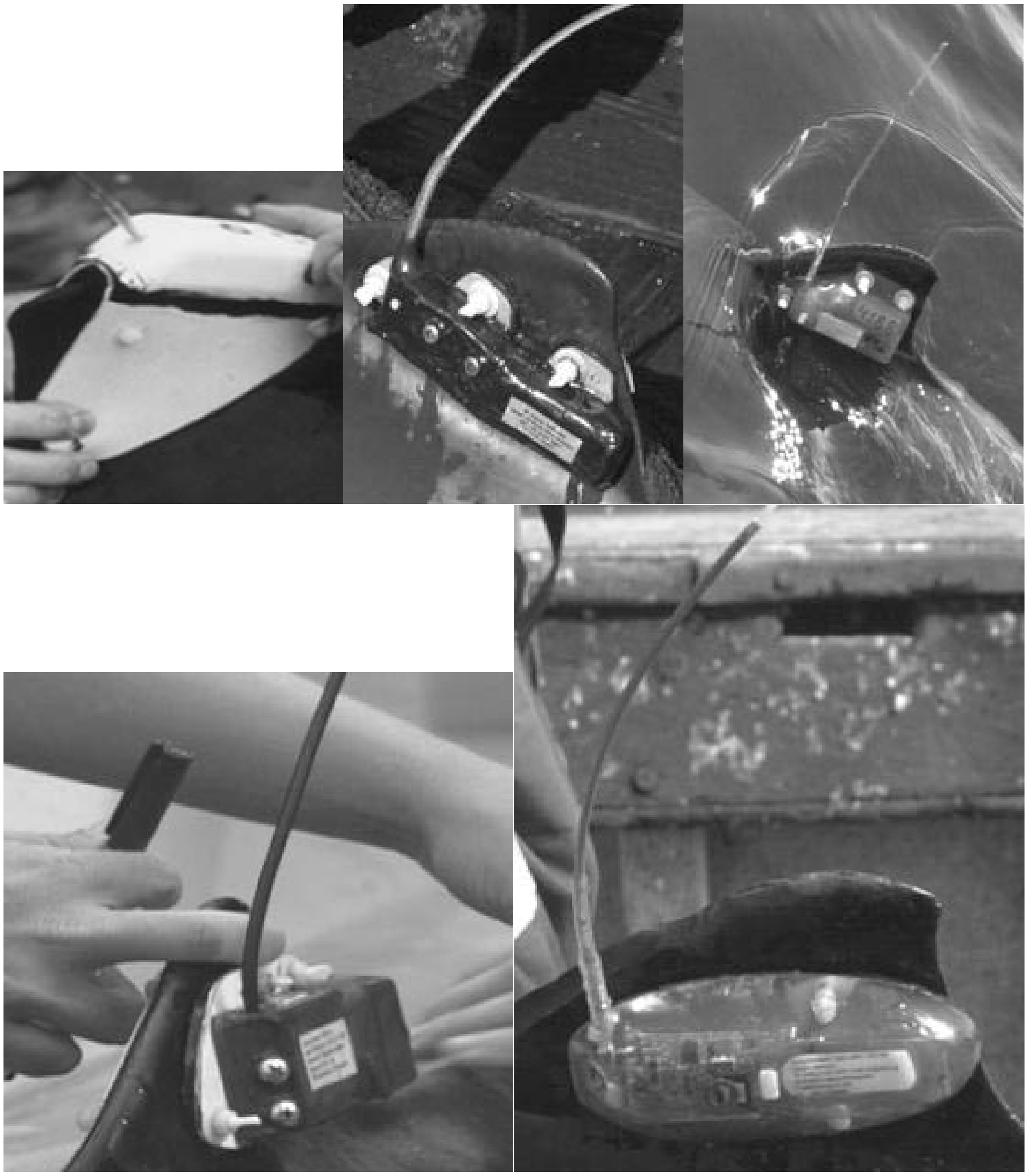

Fig. 2. Photos of some of the satellite tags deployed on harbour porpoises in Denmark. From top left SDR-T10, Kiwi 101, SDR-T16, ST-10/ST-18 and SPOT2.

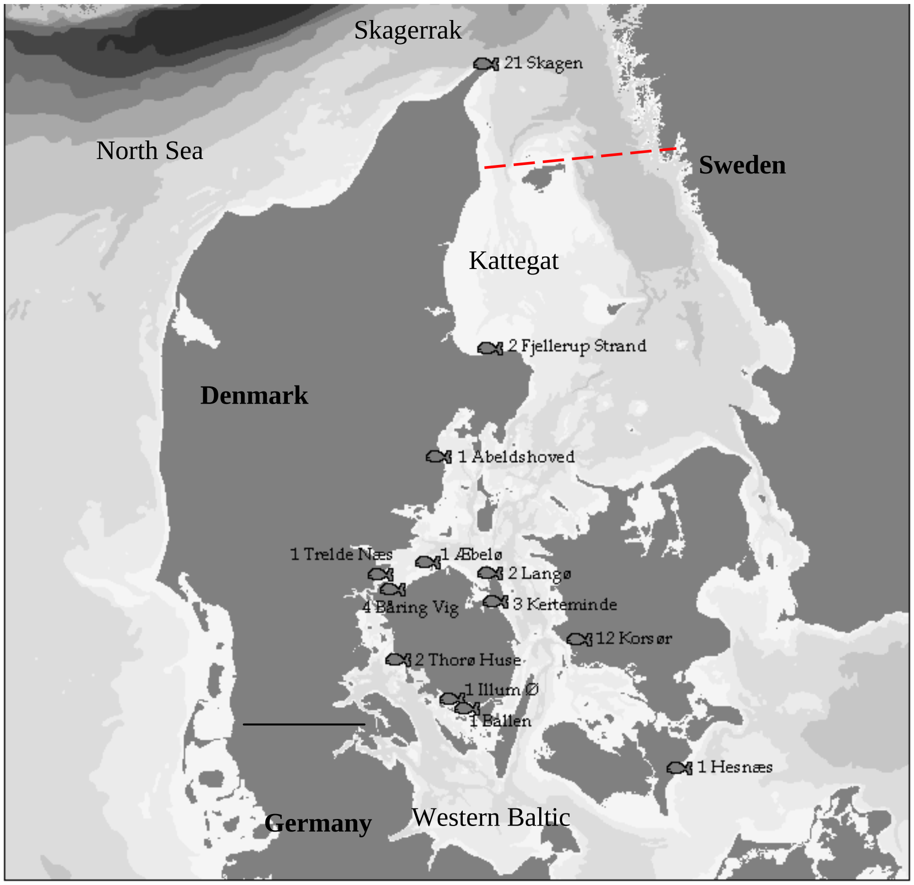

Fig. 3. Map of Denmark with the tagging sites indicated as blue fish symbols. The number of harbour porpoises tagged at each location is given in front of each location name. The red dashed line indicates the suggested population boundary.

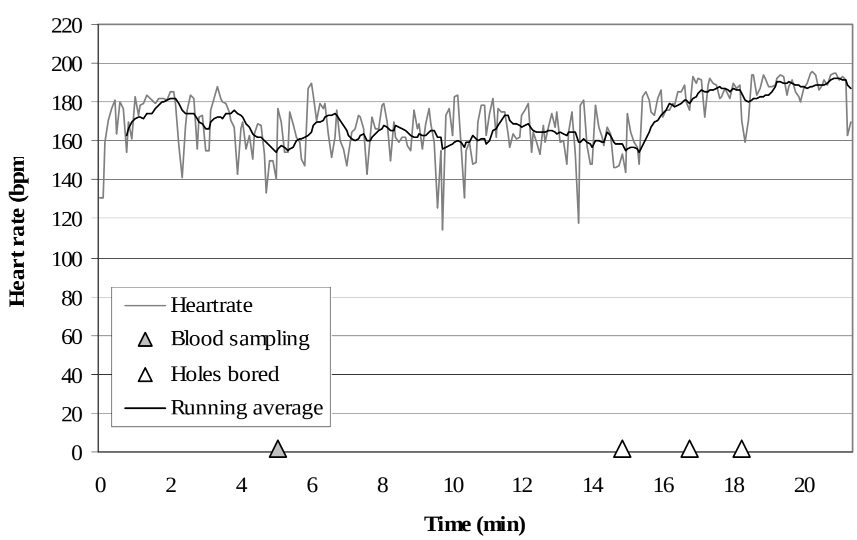

Fig. 4. Heart rate of captive porpoise during mounting of a satellite and a VHF transmitter.

Appendix 6

AGENDA

Wednesday, 11 June

9:00 Welcome, introductions, logistics, plans for information, and agree to agenda
9:15 Functional morphology of the small cetacean dorsal fin (Pabst, McLellan, et al.)
9:30 Brief review of past development of tags and attachment techniques (Scott & Wells)
9:45 Recent experiences with tag attachment

Delphinids

Spotted dolphins (Scott & Chivers)
Bottlenose dolphins (Hohn, Hanson, Scott & Townsend)
Killer whales (Hanson)

10:45 Break
11:00 *Phocoenids*

Seasonal migrations and population structure of harbor porpoises in North Sea and Baltic waters: Behavioral impact of satellite tagging on a captive animal (Teilmann)
Harbor porpoises (Westgate & Read)
Harbor and Dall's porpoises (Hanson)

Monodontids

Beluga whales (Hobbs)
Beluga whales and narwhals (Martin)

Botos (Martin)

12:30 Lunch
1:30 Lessons learned

Duration of attachment
Materials
Attachment site, number of attachment points
Size & configuration of packages

3:00 Break
3:15 Release mechanisms

Maximization of data collection
Effects on health & welfare

5:00 Adjourn for day

Thursday, 12 June

9:00 Continue discussion from previous day, if necessary
Recommendations

Appropriate sex and age classes
Attachment techniques & sites
Observation, follow-up & intervention

10:45 Break

11:00	Health & welfare Research needs Criteria for permit review
12:30	Lunch
1:30	Agree to wording of consensus report
3:00	Adjourn

Appendix 7

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