

Project Number: 900822

Project Start: Jan. 1, 2008 **Project Duration (in years):** 1

Please indicate what type of project is being proposed (mark only one).

☒	☐	☐	☐	☐
Feasibility/Scoping [Less than 100 days effort]	Development¹	Research	Infrastructure¹	Education
	☐	☐		
	Time Series	Institute Initiative		

Project Manager/PI:
George I. Matsumoto/Chris Harrold

Project Title: Dissolved-oxygen sensor and improved data recovery for pop-up archival tags

¹ Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).

1) ABSTRACT (new projects only)

Current MBA Husbandry research efforts are, in part, directed at advancing our knowledge of the physiological ecology of present and future exhibit species through the use of pop-up archival transmitting (PAT) tags. These ‘bio-logging’ devices sample depth, temperature, and light at periodic intervals (up to 1 Hz sampling rate) and archive the data in onboard flash-memory. At a pre-programmed time the tag detaches from the animal, floats to the surface, and transmits a processed summary of the data to the Argos satellite system from where it can be retrieved. Thus, these tags are often called pop-up satellite tags. Although the full archived time-series is held in non-volatile memory onboard the tag, recovery of the time-series data requires physical recovery of the tag. Floating tags can be actively recovered by locating their approximate position, which is provided by Argos, and then using radio-directional finding gear tuned to the Argos frequency (401.65 MHz).

Species we are presently working with in ongoing MBA-approved programs include white sharks, mola, Humboldt squid, mobulid rays, and tiger sharks, all of which have been successfully studied with conventional archival or PAT tags. Unfortunately, commercially available PAT tags are not presently meeting many of our requirements, because of the two general limitations discussed below. We have therefore formed a research-team (MBARI/MBA/ Stanford/Wildlife Computers) to support the development of new PAT tag technologies that address these specific limitations.

This Feasibility Study addresses two major goals. (1) Incorporate a sensor for dissolved oxygen into an existing commercially available PAT tag package. This would allow rapid progress to a useful tag for several ongoing research projects. It will also define a general procedure and working relationship that would guide and expedite development of additional sensors or tag platforms in the future. (2) Assess feasibility of technical improvements in three general areas designed to optimize recovery of data. A) Transmission of time-series data through the Argos satellite system, B) Methods for transmitting time-series data independent of Argos, C) Increased transmission time/power through modified or alternative power sources. These improvements will again be immediately directed at an existing PAT tag platform, but they will also be considered in a more general sense, because they would provide a foundation for future developments geared toward design of new tag platforms.

Targeted improvements will lead to a greater variety of sensors, which will enhance interpretation of animal behavior in regard to environmental conditions. They will also greatly improve the quality of data recovered from PAT tags. This would greatly increase MBA Husbandry’s ability to define natural parameters for optimal exhibition of living specimens. This project will also benefit any MBARI scientific goals that involve monitoring behavior, physiology and habitat utilization of deep, mobile benthic and demersal animals. Although electronic tags have been extremely successful with large epipelagic species, their use with deep-living animals has been quite limited.

2) PROPOSAL

a) The problem addressed (new projects only)

Statement of the problem

1) Oxygen sensor development. Electronic archival-tagging of marine and freshwater macrofauna has increased greatly in the last decade (Arnold and Dewar, 2004), largely due to the development of commercially available pop-satellite tags and technical improvements that have increased performance in a variety of ways. More powerful processors, larger memory, increased battery power and life, improved sensors for pressure, temperature and light, and development of new sensors (e.g. velocity and acceleration) are all examples (Muramoto et al., 2004). These methods have revolutionized our understanding of the behavioral dynamics and physiological limitations of many commercially and ecologically important species and have become the cornerstones of major international research initiatives including Tagging of Pacific Pelagics (TOPP -- <http://www.toppcensus.org/Web/Background/Overview.aspx>) and Climate Impact on Top Oceanic Predators (CLIOTOP-- <http://web.pml.ac.uk/globec/structure/regional/cliotop/cliotop.htm>).

Most archival tagging studies were initially focused on large-distance horizontal migrations, and technical improvements have addressed issues concerning the accuracy of light-based geo-location in order to trace migration paths (Teo et al., 2004; Seitz et al., 2006). More recently, a number of investigations have revealed surprising new behaviors and physiological capabilities of pelagic and mesopelagic predators, including ones that directly interact, such as Humboldt squid (Gilly et al., 2006), yellowfin tuna (Schaefer et al., 2007) and sperm whales (Davis et al., 2007). Such studies provide the basis of understanding habitat utilization in the open ocean by pelagic predators.

For example, in the cited studies, it is clear that each of these predators interacts with organisms (including each other) in the acoustic deep scattering layer (DSL). Because the DSL tends to correspond to the upper boundary of the midwater oxygen minimum layer (OML) throughout much of the eastern Pacific, the relevance of dissolved oxygen to the ecological physiology of these top predators becomes extremely relevant. The present inability to measure dissolved oxygen in archival tagging studies represents an outstanding problem. This is also true for other environmental variables such as pH, PCO₂, salinity, and chlorophyll concentration, but this proposal is limited to addressing the oxygen issue.

2) Transmission of time-series data. A second major limitation in PAT tag technology centers on the amount of archived data that can be transmitted to the Argos satellite system, which is ultimately limited by the capacity of onboard batteries that determine total transmission time as the detached tag floats at the surface (typically 10-12 days). Development of alternative power sources that would directly extend transmission time are addressed by this proposal. But another problem lies in the nature of data transmitted to Argos. In the most widely used commercially available tags (Wildlife Computer MK10), data can be

sampled at rates up to 1Hz and archived for about 1 month within current memory limitations, but the data transmitted to Argos is limited to hourly summaries of time-at-depth, time-at-temperature, and maximum/minimum depth/temperature for a programmed distribution of bin sizes.

Transmission of archived time-series data would greatly increase the power of the PAT tag platform, but the large amount of archived data far exceeds that which can be transmitted to Argos even with vastly increased battery power. A compromise solution to this problem exists in devising data-compression algorithms that can extract the most useful and salient features of the times-series data and then transmit a sub-sample of those data to Argos. Alternatively, other methods of data transmission are possible that would bypass the Argos bottleneck entirely, at least in line-of-sight applications, such as RF/microwave modems. Retrieval of even limited time-series data without the necessity of physically recovering the tag (always difficult and expensive, sometimes prohibitively so) would vastly increase the power of PAT tag technology.

Why it is important

1) Oxygen sensor development. Despite its recognized importance to nearly all metabolically active organisms, dissolved oxygen in the oceans is monitored relatively little. This is primarily due to limitations of remote sensing and the large costs involved in traditional oxygen measurements using CTD casts or moored buoy methods. Increasing the level of monitoring is important, because the position and thickness of the OML is a dynamic feature (Levin, 2003), both in the Gulf of California where substantial seasonal variation occurs (Gilly, unpublished data and personal communic.) as well as in Monterey Bay where year-to-year variation occurs (Chavez, unpublished data and personal communic. to W. Gilly). Although the OML is known to be directly linked to surface productivity and mesopelagic microbial activity, the nature and dynamics of the connections are not well understood. These dynamics of the OML in turn, impact the fauna associated with the DSL, and thus the trophic cascade ending with top mesopelagic and pelagic predators, including squids, fishes, and marine mammals – and in some cases human fishing activities. Nearshore hypoxic events related to surface productivity can also occur, as in a recent Orgeon case (Grantham et al., 2004) that remains ongoing (J. Lubchenco, personal communic.)

Incorporation of oxygen sensors into a tagged animals (or AUV) presents a relatively low cost way of greatly expanding monitoring of dissolved oxygen. Appropriate sensors for AUV's may be commercially available, but deployment on a reasonably sized animal such as a Humboldt squid, yellowfin tuna or white shark, will require engineering R&D. Incorporation of a suitable oxygen sensor into a commercially available PAT tag platform is a major goal of this proposal. This achievement will allow oxygen measurement precisely where a tagged animal is swimming, which is critically important to ongoing physiological and ecological studies relevant to MBA efforts at displaying various species. Application to mesopelagic and demersal species would also greatly benefit MBARI studies. Finally, it will permit animals to serve as oceanographic data

collectors in the same way that the TOPP program is undertaking for temperature-depth profiles. Adding oxygen to this data set would represent a major accomplishment that would benefit the broad marine biological and oceanographic communities (Gilly and Markaida, 2007).

2) Transmission of time-series data. Improvements in the amount and type of data transmitted from PAT tags to the end-user represent an equally important problem. Time-series data reveal details of animal behavior that are simply impossible to deduce from time-at-depth and time-at-temperature data, and this is dramatically illustrated in recent archival tagging studies of Humboldt squid (Gilly et al., 2006) and yellowfin tuna (Schaefer et al., 2007) off Baja California. In the case of squid, vertical velocity measurements unexpectedly revealed that these metabolically active predators appear to actively forage at hypoxic depths of 200-300 m as well as in oxygenated near-surface waters. Mechanisms underlying this ability are presently being investigated. In the case of yellowfin tuna, time-series data revealed a surprisingly large number of brief dives to depths of 200-300 m, even though time-at-depth data indicated insignificant occupancy of these depths. This type of diving activity had not been previously described for yellowfin tuna, which have generally been regarded as a truly epipelagic species.

The ability to recover time-series data like these without the necessity of recovering a PAT tag (or resorting to fishery-dependent returns of conventional, implanted archival tags) would be of major importance to all biologists studying movements and habitat utilization of pelagic, mesopelagic and demersal species and interactions between large predators and their prey, such as sperm whales and Humboldt squid (Davis, et al. 2007).

Present state of art/understanding

1) Oxygen sensor development. An initial thrust of this study will be to identify and thoroughly compare all currently available technologies for dissolved-oxygen sensing and assess their compatibility with the goal of incorporating the sensor on a PAT tag to be carried by a living animal. Commercially available dissolved-oxygen sensors are of two main types, electrolytic (including galvanic and polarographic, Clarke-type) and optical (fluorimetric). Each type has advantages and disadvantages that must be carefully considered. There are presently a variety of sensors, both packaged and unpackaged, manufactured by a large number of corporations -- 90 according to the Global Spec engineering search engine queried with "dissolved oxygen sensor"

(<http://search.globalspec.com/Search?query=oxygen%20%22Oxygen%20Sensors%22&n=10&show=total&frmtrk=refine&frmqry=oxygen>). These companies include PreSens (Precision Sensing GmbH, Regensburg, Germany), Aanderaa (Bergen, Norway), Loligo Systems (Hobro, Denmark), In-Situ (Ft. Collins, CO), Ocean Optics (Dunedin, FL), and of course Sea-Bird Electronics (Bellevue, WA). Of these, only Loligo Systems already offers an oxygen sensor module (http://www.loligosystems.com/default.asp?Index_nr=2&prod_kat=30&page=products) that can be utilized in conjunction with acoustic transmitters in animal-tagging applications (Svendsen et al., 2006). This is a galvanic-type sensor, rated

to 2,000 m depth, and of a size that is promising for incorporation into a PAT tag. We will investigate these products and potential collaborations.

Finally, a major 5-year research initiative in the UK (Oceans2025) has recently commenced and includes a theme of technology development, including development of new sensors (<http://www.oceans2025.org/>). This ambitious program is just starting, and we will make contact with them in an effort to undertake the most complete analysis of the oxygen-sensor question possible.

2) Transmission of time-series data. This goal encompasses three areas: A) Developing suitable data processing and compression algorithms that can be used to transmit time-series data through the currently used Argos system. B) Implementation of an alternative transmission method that obviates the need for Argos. C). Increasing the total time available for data transmission by extending battery life with alternative power sources.

A). Processing and compression algorithms for use with Argos. This general problem has been discussed in the literature in some detail (Fedak et al., 2002). Onboard data processing and compression for the most widely used commercial PAT tag, the Wildlife Computers MK10, is proprietary, but they are already working on the problem of sending time-series data through Argos. As part of this feasibility study we will collaborate fully and openly with the Wildlife Computers engineering staff to further explore this solution.

Processing/compression algorithms will have to be ‘smart’ and flexible enough to accommodate data from different types of animals, for example diving dynamics of squid and yellowfin tuna are quite different, and the optimal compression strategy would not be identical for the two species. Identifying what dynamic features of time-series data needs to be processed, stored and transmitted will be an important challenge that will involve both engineering and biology.

B.) Transmission methods that bypass Argos. This issue was also discussed by Fedak et al. (2002). Alternate methods for data transmission that have already been used in the context of tagging and tracking of marine animals include VHF/UHF and cell-phone modems (McConnell et al., 2004). VHF/UHF/microwave communication is limited by the need for line-of-sight access between the floating tag and a receiver, either on a ship, on land, or in the air. In geographical areas of relatively limited extent that are also close to land with coastal hills, or even mountains, these transmission methods might provide an excellent way to transmit a large set of time-series data at low cost. Such areas would include much of Monterey Bay and the near-shore California current system as well as many parts of the Gulf of California, and these locations are precisely those that much of our ongoing research effort is focused on. These methods would not be suitable for animals that migrated far offshore, as some of our species do. Again, this problem will require a solution that recognizes both engineering and biological limitations.

C. Extended transmission time. Commercially available PAT tags already utilize the smallest and most powerful batteries available (M. Braun, personal communication). Improvements in extending transmission time will therefore have to be made in the general area of battery recharging and alternate power

sources. Again, a variety of technologies exist which will require investigation, including electromagnetic generators, piezo-electric devices, and solar cells that can be used to keep a battery charged for a long period of time, thereby greatly increasing the total time available for data transmission.

References

- Arnold, G. and H. Dewar. 2001. Electronic tags in marine fisheries research: a 30 year perspective, in J.R. Sibert and J.L. Nielsen (eds.), *Electronic Tagging and Tracking in Marine Fisheries*, Kulwer, Netherlands, pp. 7-764
- Davis R.W., N. Jaquet, D. Gendron, U. Markaida, G. Bazzino and W. Gilly. 2007, Diving behavior of sperm whales in relation to behavior of a major prey species, the jumbo squid, in the Gulf of California, Mexico. *Mar. Ecol. Prog. Ser.* 333:291-302.
- Fedak, M., P. Lovell, B. McConnell and C. Hunter. 2002. Overcoming the constraints of long range radio telemetry from animals: getting more useful data from smaller packages. *Integ. Comp. Biol.* 42:3-10.
- Gilly, W.F. and U. Markaida. 2007. Perspectives on *Dosidicus gigas* in a changing world, in *The Ecological Role of Squid in Pelagic Ecosystems*, Olson, R. and Young, J. eds., **GLOBEC Reports**. In Press.
- Gilly, W. F., U. Markaida, C. H. Baxter, B. A. Block, A. Boustany, L. Zeidberg, K. Reisenbichler, B. Robison, G. Bazzino and C. Salinas. 2006b. Vertical and horizontal migrations by the jumbo squid *Dosidicus gigas* revealed by electronic tagging. *Mar. Ecol. Prog. Ser.*, 324: 1-17.
- Grantham, B.A., F. Chan, K.J. Nielsen, D.S. Fox, J.A. Barth, A. Huyer, J. Lubchenco and B.A. Menge. 2004. Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific. *Nature* 429:749-754.
- Levin, L. 2003. Oxygen minimum zone benthos: adaptation and community response to hypoxia. *Oceanography and marine Biology: an Annual Review* 41: 1-45.
- Muramoto, H., M. Ogawa, M. Suzuki and Y. Naito. 2004. Little Leonardo digital data logger: its past, present and future role in bio-logging science. *Mem. Natl. Inst. Polar Res., Spec. Issue* 58:196-202.
- Schaefer, K., D.W. Fuller and B.A. Block. 2007. Movements, behavior and habitat utilization of yellowfin tuna (*Thunnus albacares*) in the northeastern Pacific Ocean, ascertained through archival tag data. *Mar. Biol.* In Press.
- Seitz, S.C., B.L. Norcross, D. Wilson and J. Nielsen. 2006. Evaluating light-based geolocation for estimating demersal fish movements in high latitudes. *Fish. Bull.* 104:571-578.
- Svendsen, J.C., K. Aarestrup, J.F. Steffenssen and J. Herskin. 2006. A novel acoustic dissolved oxygen transmitter for fish telemetry. *Mar. Tech. Soc. J.* 40: 103-108.
- Teo S.L.H., A. Boustany, S. Blackwell, A. Walli, K. Weng, and B.A. Block. 2004. Validation of geolocation estimates based on light level and sea surface temperature from electronic tags. *Mar. Ecol. Prog. Ser.* 283:81-98

How it relates/contributes to MBARI's mission and strategic plan

MBARI's 2006 Strategic plan has three primary goals and this study addresses each one of them.

Transform and advance understanding of the most significant unsolved problems in oceanography by developing, adapting, and demonstrating innovative technologies: The development of novel sensors (e.g. oxygen) and the adaptation of existing Archival Tags to a smaller format will advance our understanding and knowledge of the environment as well as of species life history preferences.

Utilize these developments to discover and understand how the natural system operates, responds to, and interacts with anthropogenic influence: As the occurrence of dead zones increases, the ability to monitor areas with robust and sensitive sensors (oxygen and perhaps pH) would be extremely valuable in providing both event data as well as pre- and post-event data. All of this should enhance our understanding of the system and how anthropogenic input influences the system.

Transfer the knowledge gained and the technology developed to communities outside of MBARI, including policy makers, government laboratories, resource managers, and the public: The data gathered from the completion of the study will be useful to a wide variety of audiences. The outcome of this feasibility study will be of less general use, but we have initiated discussions with industry who are interested in partnering both in the feasibility study and the full proposal (if proposed and funded).

New, stunning living displays are the heart and soul of the Monterey Bay Aquarium's long-term sustainability. A strategic goal of the aquarium's 2007-2011 strategic plan is to inspire, engage and connect a large and diverse audience with the ocean and its habitats. A key strategy in achieving this goal is to continue to develop unique and cutting edge live exhibits, including marine life that has never before been on public display. Over the next few years the aquarium's research and development team will focus on jumbo squid, deep-sea jellies, molas and other species that will enhance the 2011 Outer Bay Wing remake. This proposal would directly support this strategic objective by providing improved data on environmental preferences of free-ranging jumbo squid and small molas. In the longer term, a new generation of sensors and telemetry would help us understand the environmental preferences of species for new exhibits beyond the 2011 re-opening of the Outer Bay Wing.

b) Approach to the problem (new and continuing projects)

Status of project

New Project

Results to date

New Project

Publications (from the last 5 years)

Publications of team members

William Gilly (only journal papers relevant to marine ecology)

- Gilly, W.F. and U. Markaida. 2007. Perspectives on *Dosidicus gigas* in a changing world, in *The Ecological Role of Squid in Pelagic Ecosystems*, Olson, R. and Young, J. eds., **GLOBEC Reports**. In Press.
- Gilly, W.F. 2007 Horizontal and vertical migrations of *Dosidicus gigas* in the Gulf of California revealed by electronic tagging, in *The Ecological Role of Squid in Pelagic Ecosystems*, Olson, R. and Young, J. eds., **GLOBEC Reports**. In Press.
- Sagarain, R.D., W.F. Gilly, C.H. Baxter, N. Burnett and J. Christensen. 2007. Remembering the Gulf: Changes to the marine ecology of the Sea of Cortez since the Steinbeck and Ricketts expedition of 1940. **Frontiers in Ecol. Environ.** In Press.
- Davis, R.W., Jaquet, N., Gendron, D., Markaida, U., Bazzino, G. and Gilly, W. 2007. Diving behavior of sperm whales in relation to the behavior of a major prey-species, the jumbo squid, in the Gulf of California, Mexico. **Mar. Ecol. Prog. Ser.:** 333:291-302.
- Gilly, W.F, Markaida, U., Baxter, C. H., Block, B.A, Boustany, A., Zeidberg, Reisenbichler, K., Robison, B., Bazzino, G. and Salinas, C. 2006. Vertical and horizontal migrations by the jumbo squid *Dosidicus gigas* revealed by electronic tagging. **Mar. Ecol. Prog. Ser.** 324:1-17.
- Gilly, W.F., Elliger, C.A., Salinas, C.A., Camarilla-Coop, S., Bazzino, G. and Beman, M. 2006. Spawning by jumbo squid (*Dosidicus gigas*) in the San Pedro Martir basin, Gulf of California, Mexico. **Mar. Ecol. Prog. Ser.** 313:125-133.
- Gilly, W.F. 2006. John Steinbeck, Ed Ricketts and Holistic Biology: A New Voyage to the Sea of Cortez. **Key Reporter (Phi Beta Kappa Society)** 71: 10-11.
- Markaida, U., Rosenthal, J.J.C. and Gilly, W.F. 2005. Tagging studies of the jumbo squid, *Dosidicus gigas*, in the Gulf of California, Mexico. **Fishery Bulletin.** 103:219-226.
- Gilly, W.F. 2005. Spreading and stranding of jumbo squid. **Ecosystems Observations for the Monterey Bay National Marine Sanctuary 2005:** 25-26
- Gilly, W.F. 2004. Searching for the spirits of the Sea of Cortez. **Steinbeck Studies** 15:7-13.

Gregory T.A. Kovacs (journal papers only)

- Whittington, R.H., L. Giovangrandi and G.T.A. Kovacs. 2005. A closed-loop electrical stimulation system for cardiac cell cultures. **IEEE Trans. Biomed.Engin.** 52:1261 - 1270.
- Lange, D., C.W. Stormont, C.A. Conley and G.T.A. Kovacs. 2005. A microfluidic shadow imaging system for the study of the nematode *Caenorhabditis elegans* in space. **Sensors and Actuators B** 107: 904 - 914.

- Gilchrist, K.H., L. Giovangrandi, R.H. Whittington G.T.A.Kovacs. Sensitivity of cell-based biosensors to environmental variables. ***Biosensors and Bioelectronics* 20**: 1397 - 1406.
- Droitcour, A.D., O. Boric-Lubecke, V.M. Lubecke, J. Lin and G.T.A. Kovacs. 2004. Chest motion sensing with modified silicon base station chips. ***IEICE Trans.s on Electronics, Special Issue on Wave Technologies for Wireless and Optical Communications, vol. E87-C, no. 9***:1524 - 1531.
- Droitcour, A.D., O. Boric-Lubecke, V.M. Lubecke, J. Lin and G.T.A. Kovacs. 2004. Range correlation and I/Q performance benefits in single-chip silicon Doppler radars for noncontact cardiopulmonary monitoring. ***IEEE Transactions on Microwave Theory and Techniques* 52**: 838 – 848.
- Kovacs, G.T.A.. 2003. Electronic sensors with living cellular components. ***Proc. IEEE* 91**: 915 – 929.
- Freiwald, W.A., H. Stemann, A. Wannig, A.J. Kreiter, U.G. Hofmann, M.D. Hills, and G.A.T, Kovacs. 2002. Stimulus representation in rat primary visual cortex: multi-electrode recordings with micromachined silicon probes and estimation theory. ***Neurocomputing* 44**: 407 - 416.
- Mourlas, N.J., K.H. Gilchrist, L. Giovangrandi, N.I. Maluf and G.A.T. Kovacs. 2002. An inline Osmometer for application to a cell-based biosensor system. ***Sensors and Actuators B: Chemical, vol. 83***: 41 - 47.
- Goldberg, J.L., J.S. Espinosa, Y. Xu, N. Davidson, N., G.T.A. Kovacs and B.A. Barres. 2002. Retinal ganglion cells do not extend axons by default: promotion by neurotrophic signaling and electrical activity. ***Neuron* 33**: 689-702.

Plans for 2008

During this study the Engineering Team (MBARI, Stanford and Wildlife Computers) will work closely with the Biological Team (MBA, Stanford) in all R&D efforts to achieve the stated goals. These goals are discussed individually below. Only Goal 1 is intended to produce a physical prototype of a functional product that will be both bench- and field-tested. Goal 2 is a feasibility analysis that will provide the necessary foundation for future efforts at physical implementation. Tasks for Goal 1 are thus presented in considerably more detail than those for Goal 2. It is also important to note that not all of the engineering tasks indicated below will be performed only at MBARI. Some of these tasks will be shared with personnel at Stanford and Wildlife Computers. We will seek external funding for these efforts from NSF and other sources. MBA has allocated funding toward these efforts in 2008.

Engineering/technology development

Goal 1) Incorporation of a dissolved-oxygen sensor into the MK10 PAT tag.

Task 1: Define constraints of a sensor for ultimate application in a tag carried by an animal – parameters would include size, weight, fluidic drag, power consumption, sensor resolution/accuracy, data storage/compression capabilities, packaging requirements, physical fragility.

Task 2: Carry out a ‘trade-space analysis’ for the most important interacting parameters identified in order to synthesize qualitative understanding of the design trade-offs and to better understand optimization of particular subsets and potential co-optimization with other sensors downstream.

Task 3: Identify commercially available sensors, both discrete, unpackaged sensors (e.g., PresSens) and pre-packaged sensors (e.g., Loligo Systems) and evaluate their fit with results of Tasks 1-2.

Task 4: Analyze compatibility of preferred sensors with the MK10 platform in terms of physical packaging and existing defined interface specifications. We expect to identify one or more suitable sensors for the stated goal. Nevertheless, some sensors may be deemed incompatible with the MK10 PAT tag, but could still provide a useful tag in a platform with other specific characteristics. Thus, identification of such sensors will still be valuable in a more general way.

Task 5: Integrate a specific sensor with an MK10 tag (hardware and software) in bench-top tests in order to demonstrate overall functionality, assess data-logging capabilities and the ability to successfully transmit summarized oxygen data to Argos.

Task 6: Modify MK10 packaging to accommodate a specific sensor in order to carry out pressure tests in oil-filled pressure chambers at MBARI and field tests in a seawater environment.

Task 7: Carry out field tests of MK10-Oxygen tag by attaching the unit to a Seabird SBE19plus CTD (SBE43 oxygen sensor). Tests will be conducted both in large MBA holding tanks filled with seawater and in Monterey Bay by the biological team. This will confirm accuracy and stability of the MK10-oxygen sensor in a true field situation. Alternatively these tests could be carried out with MBARI facilities in conjunction with ongoing ROV operations.

Task 8: Deploy an MK10-Oxygen tag on a swimming animal in a large holding tank. The species of animal to be tagged is not important; it only needs to be large enough to successfully carry the tag for a period of several days. Suitable species would include any being held in the quarantine tanks at MBA or at MBA tanks at the TRCC at Hopkins Marine Station. The tag will be released and allowed to transmit to Argos. This test will fully confirm the utility of the tag package and provide proof of design. The only remaining test would be to carry out field trials with a free-swimming wild animal, but this will be outside the scope of this project.

Goal 2) Improved transmission of time-series data.

We propose to evaluate the feasibility of three different, but related, ways of improving the transmission of time-series data.

A). Processing and compression algorithms for use with Argos. We will analyze methods for transmission of time-series data through Argos with the MK10 PAT tag. These efforts are already underway at Wildlife Computers, and we will be joining those efforts and working closely with them. In general, we will consider three issues. 1) Identify features of the time-series data to be

analyzed with onboard processing and subsequently saved. For example, what specific characteristics of vertical movements would be used to define a behavioral ‘event’? Should the entire event be archived in real time or at a compressed sampling rate? Should only ‘features’ of the event be archived? The definition of events and features for detection will depend on the individual species of animal tagged, so the degree of flexibility in these definitions must be considered. 2) Processing and archiving procedures selected will be analyzed in terms of compatibility with existing bandwidth limitations imposed by Argos. The specifications and frequency of Argos transmissions are fixed parameters, and these will constrain the amount and type of time-series data to be transmitted. 3) We will make initial definitions of algorithms necessary to process the data and compress it in the desired manner for transmission. In this phase, it will be essential to maintain a clear understanding of the potential for data loss given unexpected situations that might violate the underlying compression assumptions. 4). Finally, we will incorporate the identified algorithms into software for the MK10 controller, at least in a preliminary fashion.

B.) Transmission methods that bypass Argos. We propose to evaluate the feasibility of alternate methods for transmission of the features of time-series data to be defined in A). Methods to be investigated include alternative satellite systems (e.g., INMARSAT), cell-phone modem technology, and direct VHF, UHF or microwave transmission. A simple trade-space analysis will be carried out considering parameters such as size, power requirements, bandwidth, throughput limitations, and geographical limitations (e.g., line-of-site restrictions, etc).

C. Extended transmission time. This area will also be addressed in a preliminary way through an analysis much like that in B) but focused on alternative power sources that could be used to maintain charge on a battery than is presently used in the MK10 PAT tag in order to extend total transmission time before battery failure. If this time could be extended indefinitely, it might be possible to transmit a very large amount of time-series data even given the limitations imposed by Argos. Success in this venture might also permit an actual reduction in size of the battery currently used with the MK10, thereby reducing total package size. A variety of alternate power sources will need to be considered, including electromagnetic generators, piezo-electric devices and solar cells.

Sub-goal A) would provide the most rapid path to a useful, though perhaps not yet idealized, product. Results from A) will also provide essential input for Sub-goal B). Sub-goal C) is relevant to both of the other sub-goals. Again, we will primarily focus on software and hardware modifications of the MK10 platform, because this provides the most direct way to a widely useful product. Nevertheless, our analyses may identify excellent solutions that are incompatible with the MK10 platform. This will also be an important result that will serve to guide future design of any alternative tag platform.

Field programs

The only field component of this project (Goal 1, Task 7,8) can be carried out independently at MBA and Hopkins Marine Station, although Task 7 would be best carried out by MBARI in conjunction with ongoing ROV operations.

Data (availability outside project team, uniqueness)

The results of this work, in the form of trade-space analyses, identification of promising technologies, and small data sets from bench and field testing, will be shared with our team member at Wildlife Computers and possibly contribute to the development of a future commercial product. We believe that these results will be unique, as we know of no other group pursuing these issues.

Significant changes from previous project proposal (continuing projects only)

Not applicable

c) Specific deliverables (new and continuing projects)

We expect to fulfill Goal 1 and deliver a final, working prototype of an MK10 PAT tag carrying a sensor for dissolved oxygen that can be deployed on a living animal in a marine environment.

We will produce a written, preliminary analysis of each sub-goal in Goal 2. It is hoped that this work will provide the foundation for future development of physical devices that incorporate the identified technologies.

Depending on the outcome of research on the stated goals, we will consider developing a proposal for submission to NSF (or some other external funding agency) as well as MBARI for a Development Project.

d) Project team (new and continuing projects)

Project Manager: George I. Matsumoto, Senior Education and Research Specialist,
MBARI

PI: Dr. Chris Harrold, Director of Conservation Research, Monterey Bay
Aquarium

Engineering Team

Paul McGill, Electrical Engineer, MBARI

Brett Hobson, Mechanical Engineer, MBARI

Dr. Gregory T.A. Kovacs, Professor of. Electrical Engineering, Center for
Integrated Systems, Stanford University

Melinda Braun, CEO and Technical Director, Wildlife Computers

Biological Team

2008 Proposal Process – Internal-Only Projects
Submission Deadlines: Phase I – August 14th, Phase II – September 27th

John O’Sullivan, Monterey Bay Aquarium, Curator of Field Operations
Dr. William Gilly, Professor of Biological Sciences, Hopkins Marine Station,
Stanford University

e) Project lab space (new and continuing projects)

We expect that existing laboratory space accessible to Hobson and McGill to be sufficient for this work

3) BUDGET JUSTIFICATION (new and continuing projects)

\$500 to cover mileage and meals for MBARI staff to meet with external collaborators (MBA and Stanford team members)

2008 Proposal Process – Internal-Only Projects
Submission Deadlines: Phase I – August 14th, Phase II – September 27th

4) MILESTONES (new and continuing projects)

Milestones for Goal 1

Goal 1	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	Total Resources² for each resource category for all milestones listed here
Milestone Date	2/15/2008	4/15/2008	7/15/2008	11/15/2008	12/15/08	
Milestone Description	Trade-space analysis: Tasks 1-2	Identify specific sensor: Tasks 3-5	Sensor integration: Task 6	MK10 package modifications and pressure tests: Task 7	Field tests: Tasks 8-9	
EE	3	3	5		2	13
SE						
ME	3	3	5	3	2	16
Support Engineering						
EE Tech			3			
SE Tech						
ME Tech				5		
Machine Shop						

² This number should be the same number you entered on the resource requests for this particular resource.

2008 Proposal Process – Internal-Only Projects
Submission Deadlines: Phase I – August 14th, Phase II – September 27th

Milestones for Goal 2 – Sub-goals A-C are individually labeled.

Goal 2	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	Total Resources³ for each resource category for all milestones listed here
Milestone Date	3/01/08	6/01/08	7/15/08	8/15/08	12/15/08	
Milestone Description	A) Define features of time series data to be processed, saved and transmitted within limits imposed by Argos.	B) Trade-space analysis for alternate transmission methods.	A) Define data compression algorithms. C) Identification and trade-space analysis of feasible alternate power sources.	Submit Year 2 Development and/or NSF proposal if appropriate (this would also include Goal 1).	A) Trial incorporation of identified algorithms into MK10 controller software.	
EE	2	2	6	3	1	14
SE						
ME	2	2	6	3	1	14
Support Engineering						
EE Tech						
SE Tech						
ME Tech						
Machine Shop						

³ This number should be the same number you entered on the resource requests for this particular resource.

2008 Proposal Process – Internal-Only Projects
Submission Deadlines: Phase I – August 14th, Phase II – September 27th