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Review

Marine animals as platforms for oceanographic sampling: a "win/win" situation for biology and operational oceanography

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Abstract The development and deployment of logging and telemetry equipment on wide ranging marine animals has provided a wealth of data on their movements and behaviour. We can now predict, within reasonable limits, where many species go, which parts of the water column they will visit and when they will go there. But we also need to know more about the environment through which they move in order to understand their biology and the potential risks to their population status. Additionally, there is a need for near real-time monitoring of ocean processes for long-term weather and climate analyses and forecasting. Developments in sampling and data retrieval devices have made it possible to create a synergy between the biological studies of marine vertebrates and oceanographic studies used to describe and predict changes in the ocean atmosphere system. We can use larger marine species as platforms of opportunity to gather detailed oceanographic information. Animals can collect information from logistically difficult areas, at fine temporal and spatial resolution at relatively low cost. I will discuss some technological opportunities that are currently available, the results of ongoing projects and one "proof of concept" study with the hope of stimulating interest across the technical, oceanographic and biological communities for such an approach.

It seems certain that the need for timely, high resolution oceanographic information required for understanding the distribution of marine animals and for the development of increasingly fine resolution physical models will grow more rapidly than the funding available to collect that data. By using animals as platforms, we can close the gap between resources and requirements.

key words: telemetry, foraging, salinity/temperature profiles, modelling, climate change

Introduction

Telemetry and bio-logging devices are returning increasing amounts of information about marine animals from all the major taxa of top predators, including fish, reptiles, birds and mammals. In ever-increasing detail, these devices provide information on where the animals go, how they behave and, to some extent, provide information on their immediate environment. However, understanding the factors that determine the distribution of wide ranging marine animals requires a more general understanding of the physical and biological structure of the oceans than spot samples of environmental parameters can provide. Animal-derived data needs to be integrated with more synoptic oceanographic approaches. But it is

often the case that when we look for data on the oceanographic conditions in areas through which the animals move, we find it is incomplete or lacking. This can be because the animals utilize areas of ocean that are poorly known because of their inaccessibility or as the result of other logistic constraints. It is also often the case that we need information on a finer spatial or temporal scale than oceanographic models can provide. This perceived gap between what we as biologists would like to know about ocean structure and the limited information available to describe it appropriately provides motivation for us to supply more environmental data from the tags we apply, using the animals themselves as oceanographic samplers. Oceanographers too are sometimes limited by a lack of data to build and test their models. It is therefore not surprising that the idea of using marine animals as sampling platforms has grown among both biologists and oceanographers alike.

This is not a new idea. The earliest published reference to the approach I have found is from a U.S Navy report written by Evans and Leatherwood in 1972 but I am sure that it occurred to scientists long before that. Indeed, the links between bio-logging devices for use on marine mammals and oceanographic measurement goes back to the very origins of the ideas for monitoring dive behaviour. Gerry Kooyman in his book, *Weddell Seal*: *consummate diver* (1981), recounts how Pers Scholander got the idea for a dive recorder that could be attached to whales from a description written by Lord Kelvin in the 19th Century. Lord Kelvin developed the idea to take soundings from a moving ship based on the compression of air in a capillary tube containing pigment. It was this original oceanographic application that indirectly sparked the ideas for Kooyman's pioneering work developing dive recorders.

But while the idea of using animals as oceanographic platforms is not new, the technological tools to produce effective monitoring equipment have only recently become available, because of the availability of very small, low power microelectronics and computing techniques. Additional impetus is added to this development by ever increasing demands for oceanographic data. These demands are certainly felt by the biologists wanting to understand the distribution of marine animals and how they interact with the marine environment but they are also driven by the data requirements of the oceanographic community itself. The importance of near real-time monitoring of ocean processes for long-term weather and climate analyses and forecasting is increasingly being recognized. Innovative remote samplers such as moorings, buoys, gliders etc. are being developed, each of which can return data on rapid timescales. Ultimately, programs such as the Global Ocean Observation System (GOOS) will enable the assimilation of such near real-time data into state-of-the-art general circulation models. One important purpose of these is to accurately represent and predict climate variability on seasonal and longer timescales. Using larger marine top-predators to carry instruments to collect such data can play a significant role in this effort.

While the opportunities presented by this approach may not yet be widely recognized in the oceanographic community, such recognition is rapidly developing, particularly within multidisciplinary groups brought together by pioneering integrated studies such as TOPP (Tagging Of Pacific Pelagics) as discussed by Barbara Block and Dan Costa at this meeting. This large-scale pilot project has been supported in part by the Census of Marine Life project (CoML) funded by the Sloan Foundation. This foundation initiated the project to provide a stimulus to large scale, cross-disciplinary exploration of the seas. Funding through the US National Oceanographic Partnership Program (NOPP), administered by the Office of Naval Research has helped to advance the technological developments needed to develop equip-