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SD Workshop

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Future Directions in Bioluminescence Research

EXECUTIVE SUMMARY

The purpose of this workshop was to review our current understanding of marine bioluminescence and to outline important areas of emphasis for future research and technology development. Within the context of U.S. Navy interests, the primary concern is the impact of bioluminescence on detectability or risk of detection of a variety of operations. The basic questions that need to be answered are: (1) What is the probability of detection? (2) How far into the future can we predict that probability? (3) And what is the degree of certainty for any given prediction? Emphasis was placed both on near term solutions, based on the employment of current technology and modeling, and on longer term basic research needs.

Sources of bioluminescence:

In terms of current understanding, we now have a good knowledge base of which marine organisms are bioluminescent. In most cases dinoflagellates are the dominant source of stimulable bioluminescence and species in only a few genera account for the majority of observations. These are: *Noctiluca, Pyrocystis, Protoperidinium, Gonyaulax* and *Lingulodinium.* Amongst the zooplankton, copepods are generally the dominant source in the upper ocean and they are almost invariably species of the genera *Metridia* or *Pleuromamma*. Because the gelatinous zooplankton (medusae, ctenophores, siphonophores and appendicularians) can occur in significant numbers and are such high intensity emitters they can also be significant contributors to the bioluminescence potential. However, because they are quite fragile, they are not easily sampled and therefore their degree of contribution to the bioluminescence potential is not well known.

Stimulation of bioluminescence:

Background bioluminescence is generally low, especially as compared to flow stimulated bioluminescence. Conditions that stimulate bioluminescence have been most extensively studied in dinoflagellates. These studies have revealed that the threshold for stimulation occurs at a shear stress level of 0.1-0.3 Newtons $\bullet m^{-2}$ and that there is no difference between laminar and turbulent flows at equivalent shear stress levels. They have also revealed that increases in bioluminescence occur primarily because more organisms are being stimulated, not because individuals produce more light with increasing stimulus strength. Therefore, the photon flux generated by a moving object is related to the thickness of the boundary (shear) layer, the volume of the wake, and the abundance of bioluminescent dinoflagellates.

Aggregations of bioluminescent organisms:

There can be sufficient light to highlight moving objects in the water at concentrations of less than 100 dinoflagellates l^{-1}. In those few places where coastal monitoring of dinoflagellate populations has been conducted, it's been found that the abundance of bioluminescent dinoflagellates generally equals or exceeds this value. Under extreme circumstances, such as red tide blooms, bioluminescent dinoflagellate concentrations can reach 3 x 10^7 cells l^{-1}. Dinoflagellates have generation times of only a few days, therefore, under optimum conditions, growth can be explosive. The latter conditions include: (1) development of a thermocline and a stable upper mixed layer above the critical depth (depth above which organic material generated during photosynthesis exceeds the losses from all other sources and the phytoplankton population starts to grow) (2) high nutrient concentrations and (3) high light intensities.

Aggregations of zooplankton also occur. For example, thin layers (0.5 m thick) of bioluminescent copepods accumulate at density discontinuities in the water column where they can result in intense peaks of bioluminescence (2.0 x 10^{11} photons l^{-1}). These are behavioral aggregations, which are due to animal orientation to some cue, such as a food source, or other environmentally favorable condition.

Measurements of wavelengths:

Peak emission for most of the planktonic sources of bioluminescence is around 470-480 nm (blue). Full width at half maximum is approximately 50 nm for the dinoflagellates and approximately 75-80 nm for the copepods and gelatinous zooplankton.

Measurements of photon flux:

Measurements of bioluminescence in the ocean encompass a wide range of scales and sampling methods: (1) Coarse-scale measurements (less than one to tens of kms) have been made using airborne intensified cameras to monitor organisms, such as fish schools and whales, and objects, such as ships and submarines by the bioluminescence that they stimulate as they move through the water; (2) Fine-scale measurements (1-100 m) have been made with bathyphotometers that pull water, containing organisms, through a light-tight chamber where a light detector measures bioluminescence that is stimulated by some turbulence generating mechanism. (3) Micro-scale measurements (1-100 cm) have been made with a large screen imaging system that identifies individuals based on their species-specific bioluminescent displays and maps their position in three-dimensional space. The workshop discussed possible future developments at all of these scales of measurements.

Modeling and prediction:

At present there is little to no capability for predicting bioluminescence potential in coastal waters except to use climatology derived from sparse data holdings or assuming relationships to primary productivity. As a first cut at developing a predictive capability the workshop outlined several areas for emphasis:

- Mine existing bioluminescent plankton databases and pool the data in a web-based data management system to provide a first cut at seasonal variability of species composition.
- Determine how effectively bioluminescence can be used as a passive tracer over a 24-96 hour period i.e. how effectively can existing circulation models be used to predict bioluminescence given an initial measured field?
- Continue efforts to determine whether bioluminescence correlates with other oceanographic measurements. At present there is limited confidence in being able to correlate bioluminescence with chlorophyll fluorescence i.e. primary production, but, because so many of the bioluminescent plankton are grazers, there may be a better correlation between bioluminescence and secondary production. If such a correlation could be documented, the interest of the oceanographic community in bioluminescence would increase and consequently so would the data base.
- Efforts should be made to incorporate bioluminescence measurements into existing observation networks and environmental observatories.

Future needs and recommendations:

There was a consensus that making more measurements of bioluminescence was necessary. Good predictive models rely upon abundant real data and there is a paucity of the latter presently available to the general scientific community. There are relatively few sensors and platforms in current operation, and the availability of data is limited. Moreover, the lack of inter-calibration information for past bathyphotometers further complicates the use of the data that is available.

The workgroup reviewed the suite of sensors presently available to the community to determine whether any of these instruments or systems might serve as a prototypical starting point for developing a next generation commercial sensor. These need to be affordable, intercalibrated and robust sensors. Once available they should be integrated into existing multidisciplinary research programs.

We need to define the relevant space-time scales driving annual and/or seasonal variability of bioluminescent plankton at a range of coastal sites as well as characterize the relative magnitude and importance of episodic events such as red-tides and gelatinous zooplankton blooms to the bioluminescence potential of coastal regions. One important first step toward achieving this goal will be putting bioluminescence monitors at long-term installations.

Additional advancements may be made through laboratory studies. Coupled population models require detailed knowledge of the life cycles of key taxa. For example, when do dinoflagellates enter a sexual phase and how does this affect population dynamics? More information is also needed about how environmental and growth conditions cause variability in light emission, especially with regard to why some strains of dinoflagellates are luminescent while other strains of the same species are not. It is possible that some of this work can be accomplished with cultured organisms. Although cultures of luminescent dinoflagellates are now routinely maintained in many laboratories the same needs to be done for luminescent copepods.

Transitioning:

Discussion focused on R&D efforts that have been effectively transitioned to the fleet. Transition required a defined receiver with an established means of "buy-in". There must be clear objectives, deliverables, research exit criteria, and there must be active exchange and feed back between the receiver and the producer from inception through to final delivery. The ultimate challenge is to produce products that can provide knowledge that can be delivered anywhere, anytime, regardless of bandwidth that will provide a fully integrated, seamless representation of the battlespace environment and that can be used in system acquisition, simulation based training, and mission planning.

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