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Analysis of Fleet Reports of Bioluminescence in the Indian Ocean

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(U) From June 1980 to June 1981, units of the Seventh Fleet stationed in the Indian Ocean have sent reports of bioluminescence and ancillary data to the Naval Research Laboratory to aid its study of the geographical and seasonal distribution of bioluminescence in the oceans. The results of the analysis of these reports is presented in this publication. The appearance of characteristic bioluminescent phenomena, including displays, is described.

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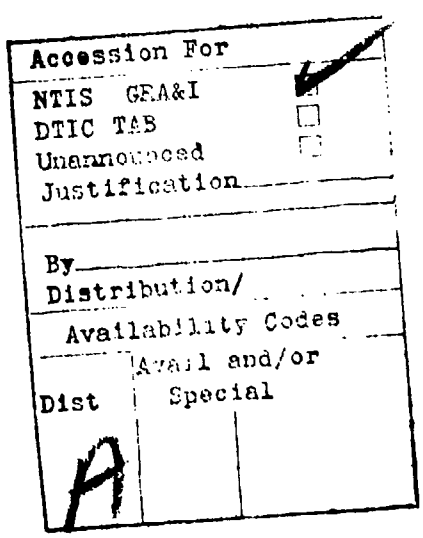

ANALYSIS OF FLEET REPORTS OF BIOLUMINESCENCE IN THE INDIAN OCEAN

INTRODUCTION

By common consensus, the Indian Ocean is considered to be the richest area in the world for marine bioluminescence [1-5]. This is especially true of the Arabian Sea region. Also in the Arabian Sea, bioluminescence is known to exhibit yearly rhythms associated with the southwest and northeast monsoons [1-10]. However, attempts to correlate occurrences of bioluminescence with various meteorological or environmental conditions, such as haze, smooth seas, or water temperature, have failed, largely due to lack of enough long-term data to permit statistical analysis.

The presence of the Seventh Fleet in the Arabian Sea area offered a rare opportunity to gather long-term data on bioluminescence occurrence and potential correlative factors simultaneously from a large number of platforms. Unfortunately, the limited scientific capability of military ships precluded gathering data on many elements of interest, such as levels of nutrients or dissolved oxygen in the water, population identifications and counts of various organisms, especially dinoflagellates, or chlorophyll fluorescence measurements. Also a desire to avoid overworking the observers, coupled with the inability to handle the vast amounts of data that would have been generated by a request to systematically report negative as well as positive observations, led to a request for positive observations alone. Nevertheless, even with these limitations it was felt that useful information could be gotten with the cooperation of the Fleet. Accordingly a format for bioluminescence and supplemental observations was prepared by the Naval Research Laboratory (NRL) and the Office of Naval Research (ONR), and a request was sent to the Fleet that bioluminescence be reported according to this format. The response has been very positive. Over a one-year period, 103 reports have been forwarded to NRL for analysis. This report contains the results of that analysis.

METHODS

The sole source of data in this report was the bioluminescence reports from units of the Seventh Fleet. The report format consisted of five parts. The first part asked for the location and time of the observation and details about the source and nature of the disturbance that produced the bioluminescence. The second part requested details on the weather and moon. The third and fourth parts asked for details of the phenomenon, including a subjective description and whether or not a low light level device was used. The fifth part asked for any supplemental data available, such as bathythermograph information. These reports were collected and examined at NRL, and the information was compared to conditions called for under various theories concerning bioluminescence occurrences. All reports began as eye observations, although low light level instruments were used a number of times to observe significant features. For reasons mentioned above no attempt at rigorous statistical analysis was made.

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RESULTS, DISCUSSION, AND CONCLUSIONS

Seasonal and Geographical Distribution

Figures 1 and 2 show the distribution of reports received grouped by quarters. On a monthly basis, 23 reports were received from November, 20 from December, 16 from January, 14 from February, 10 from September, and 4 or fewer from each of the remaining months. This is the first suggestion of a peak in bioluminescence in November-December. However, this temporal distribution may reflect the movements and occupations of the Fleet, the interest of the observers, and the dissemination of the request for reports more than actual seasonal variations in bioluminescence. Likewise, the spatial distribution of the reports reflects the movements of the Fleet more than the real spatial distribution of bioluminescence. In fact, one ship apologized for reporting from outside the Arabian Sea since it had the misconception that only reports from the Arabian Sea were desired. Statistical difficulties in interpreting reports of this kind are discussed by Turner [1,2] and Lynch [5,11].

These reports must be compared to the large body of bioluminescence data already existing for this region. When this is done, there appear to be more incidents of bioluminescence outside of the peak times than had been previously thought. This suggestion has also been made by Lynch [11].

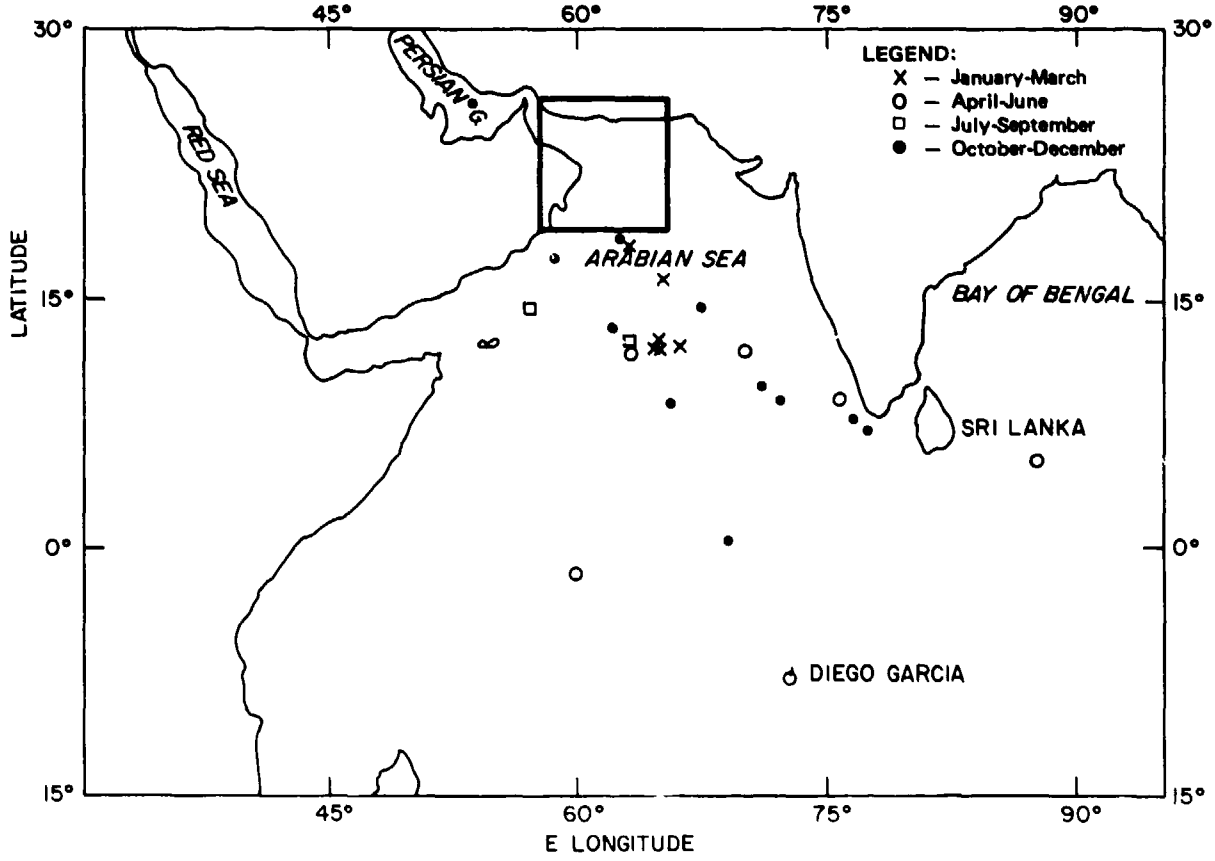

Fig. 1 — The distribution of sightings of bioluminescence by the Seventh Fleet in the Indian Ocean from June 1980 to June 1981. The square indicates the area shown in Fig. 2.

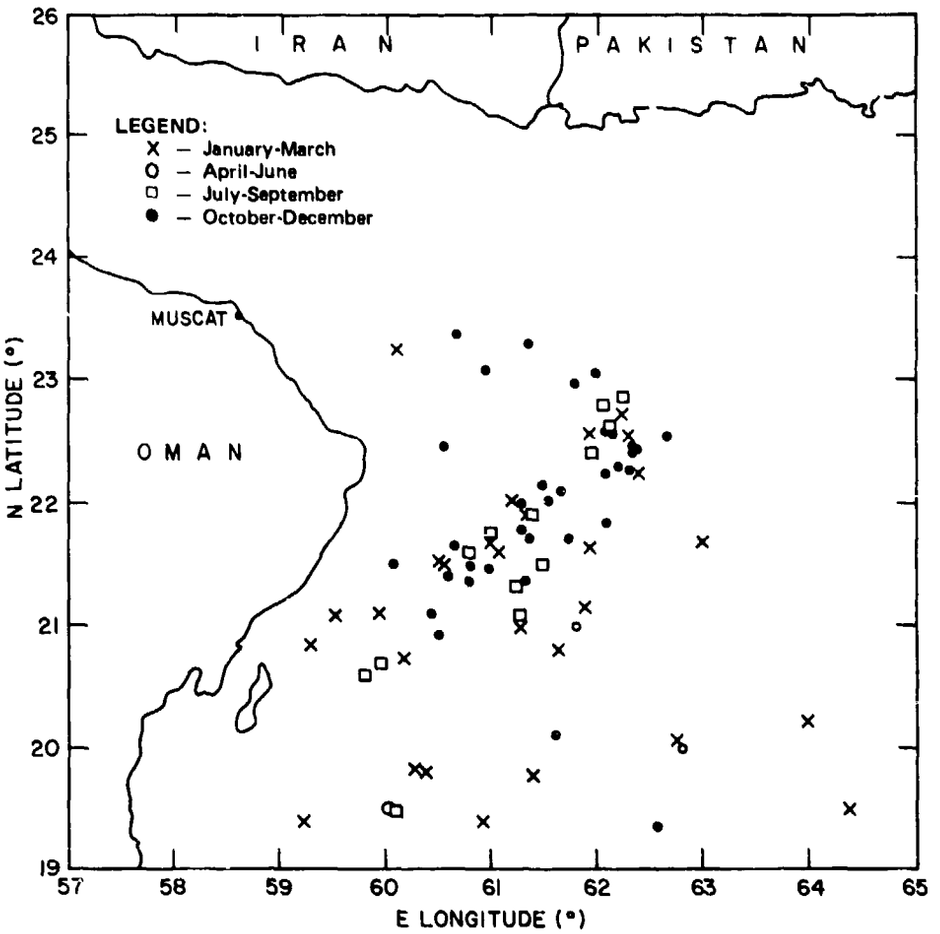

Fig. 2 — Expanded map of a portion of the Arabian Sea showing sightings of bioluminescence by the Seventh Fleet

Correlation with Environmental Data

Bioluminescence occurred whether the sky was heavily overcast, clear, or in between. No correlation with rain could be found. Bioluminescence was observed with winds from 0 to 30 knots and in sea states from 0 to 4 (Beaufort). In short, there appeared to be no correlation with meteorological factors. This conclusion was also reached by Glahn [9].

Insufficient reports of surface temperature or bathythermograph readings were made to attempt correlations with water temperature or salinity or thermocline position.

The great majority of reports came near the dark of the moon, or when the moon was not in the sky or was hidden by clouds. However, this result is most likely due to masking of bioluminescence by bright moonlight or by the interference of moonlight with the dark adaptation of the observers. Most planktonic luminous organisms are not photically responsive. Those that are generally are not disturbed by the intensity of moonlight. Lynch [11] reported finding surface bioluminescence in plankton tows under all conditions of moonlight. Of the reports analyzed herein that were made under bright moonlight, only two mentioned a decrease in the bioluminescence. One of these

was almost certainly due to the effect of moonlight on the observer. The second cannot be completely explained. However, from the description of how the bioluminescence responded to light from a searchlight, it is likely that the ship was passing through a concentration of luminous ostracod crustaceans. Some ostracods are known to be photically stimulable [12-14] and consequently could respond to bright moonlight. For these reasons it is not likely that a correlation exists between bioluminescence occurrences and the phase of the moon.

Characteristic Bioluminescent Phenomena

Turner [1,2] provides a classification scheme for bioluminescent phenomena according to appearance, stimulus, and probable causative organism. According to this scheme most of the luminescence observed came from mechanically disturbed "microplankton." Under this category all four appearance subcategories were seen.

The most commonly observed phenomenon was "disturbed water luminescence." All reports of luminescence in wakes and bow waves fall in this subcategory. Some bioluminescence was quite bright, with one observer reporting being able to read the awards on the bridge wing. Another reported that it interfered with night vision. Still another reported being able to read the print in a book at a height of 11 m above the sea surface and to see the bow wave and wake of another ship. Long wakes were also observed.

Patches of luminescence, usually oval-shaped, were frequently seen in conjunction with disturbed water. These patches would fluctuate, flash, roll, move rapidly and/or irregularly, explode, and behave in other varying manners. They ranged in size from about one meter along the long axis to thousands of square meters in area. They occurred from the surface down to 10 or 12 m and frequently changed depth as they moved. Much of the more erratic behavior occurred as the observing ship approached a patch. Very often observers would identify the patches as individual porpoise-size fish or schools of fish. When the patches appeared featureless to the eye, the use of low light level devices usually revealed fish. Only twice did observed patches of bioluminescence remain featureless when observed with a low light level device. From these observations one can suggest that most patch-type luminescence is likely caused by fish or fish schools, and that Turner's subcategories of "flashing" and "fluctuating" patches should be dropped and the whole placed in the "disturbed water" subcategory. Other evidence supports this suggestion. Lindner [15] has stated that patches of similar appearance and behavior were used by fishermen to locate fish schools at night off the coast of California. Roithmayr [16] and Cram [17,18] have published photographs of individual fish and fish schools outlined in bioluminescence that resemble the description in the reports.

One ship reduced speed while an observation of bioluminescence around the ship's hull was being made. The observer recorded that the width of the luminescent surface layer "decreased from 3 feet to 1 foot. Display illustrates textbook description of boundary layer and laminar/turbulent fluid flow along hull." Another ship changed course during an observation of bioluminescence, so that it was alternately running with and against the direction of the swells. The observer noted that luminescence was greater in both intensity and duration when the ship was moving with the seas than against them. Three reports of luminous patches and wakes commented that such phenomena were seen almost every night. Clearly bioluminescence was so common that it was not being reported every time it was observed.

Bioluminescent Displays

Four reports of "milky seas" were received. In all cases the luminescence was visible to the horizon, but no features were seen. One theory of milky seas is that they are caused by luminous bacteria feeding upon a decaying blue-green alga, *Oscillatoria erythraea*, which is known to form slicks on the surface [1,10,19]. Waves and wind frequently arrange these slicks into bands, which are sometimes observed in milky seas. The lack of banding observed here lends no support to this theory.

One of the most unusual luminescent phenomena is the "phosphorescent wheel." Descriptions of wheels have frequently appeared in the literature. The first collection of such reports was made by Kalle [20,21], who theorized that they were caused by seismic disturbances. According to his theory, such disturbances would produce wheels in shallow water under certain conditions, and "exploding balls" of luminescence in deep water. An "exploding ball" is a ball of light that rises from the depths and bursts at the surface into a large patch. One report each of exploding balls and phosphorescent wheels was received. The report of the exploding ball, however, did not follow the classical description. Instead, small grapefruit-sized balls of luminescence appeared spontaneously only a short distance below the surface, rose like an air bubble, and burst at the surface into a patch only a few diameters larger than their original size. Whether this phenomenon is the same as that described by Kalle is uncertain. The description of the phosphorescent wheel, however, was truly classic. The wheel first appeared as a strobe light or rotating beacon, then it changed to a linear wave-like pattern, and finally it turned into groups of concentric waves of light dispersing from numerous centers slightly below the surface. This display was seen in the Persian Gulf, a shallow-water area known for numerous wheel displays. A second theory of the phosphorescent wheel suggests that it is the result of an optical illusion due to distortion of perspective and parallax [22]. According to this theory, wheels should be seen only in very smooth seas, calm winds, and at least partly overcast skies with rain showers occurring before or after, but not during, the observation. Weather conditions during this observation were a completely clear sky, no rain, and moderate winds and seas. Accordingly, no support is given to the optical illusion theory. Other collections of wheel reports have been made by Turner [1], Staples [3], and Ley [23]. Other theories of wheels have been outlined by Lynch [24,25].

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