EARTH OBSERVATION BASED ASSESSMENT OF ANTHROPOGENIC STRESS TO CORAL REEFS – A GLOBAL ANALYSIS

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1. INTRODUCTION

Coral reefs are very fragile and sensitive. Marginal change in the reef environment can have detrimental effects on the health of entire coral colonies. A multitude of natural and anthropogenic reef stressors have been identified, including hurricanes [1] and seawater temperature changes [2] on the one hand and agricultural sewage discharge, polluted runoff from urban areas [3] and tourist overuse on the other hand. The widespread distribution of coral reefs and their occurrence in remote areas make the use of remote sensing data the most practical approach for a global monitoring of reef conditions and stressors. To date there has only been one single global survey of anthropogenic stress on coral reefs categorizing potential human impact in a set of risk classes [4]. In this paper a remote sensing approach to assess potential anthropogenic stress to coral reefs worldwide is presented. Three anthropogenic activities known to have adverse effects on coral reefs are analyzed using nighttime lights data derived from the Defense Meteorological Satellite Program (DMSP) produced at NOAA/NGDC [5]. Artificial night lighting is an excellent proxy measure for indirect impacts like human associated chronic water pollution. A growing body of evidence indicates that artificial sky brightness is a stressor for many reef organisms and can have direct ecological consequences [6] like disrupted spawning and forage cycles. A lights proximity index is calculated, measuring the distance of coral reef sites to each of the stressors and incorporating the stressor's intensity. The results are presented on a global and regional scale as colorized raster maps and region tables. The outcome should raise and encourage global ecological awareness and can be a useful input for the implementation of reef conservation projects.

2. DATA

In the presented project two datasets are used. The first is a global product derived from the DMSP Operational Linescan System (OLS). A cloud-free composite of nighttime lights was produced for 2003 using data from DMSP satellite F-15 [7]. To identify the best nighttime lights data for creating an annual composite a set of conditions was kept: Only the center half of the orbital swath is to be used (best geolocation and sharpest features); sunlight and moonlight must not be present and also no solar glare contamination is allowed; last and most important is the exclusive use of cloud-free images (based on thermal detection of clouds). Nighttime image data from individual orbits meeting these criteria are the basis for a global latitude-longitude grid with 30 arc second resolution cells. This grid cell size corresponds to approximately one square kilometer at the equator. Background noise and land based fires were filtered out. The remaining lights were divided into three thematic categories with all of them posing potential threat to coral reef ecosystems: (1) electric lighting from human settlements and lit facilities on land, (2) gas flares, and (3) heavily lit fishing boats.

The second database is a global spatial compilation of coral reefs. The data was obtained from Reefs at Risk [4] and originates from the United Nations Environment Programme (UNEP), World Conservation Monitoring Centre. Initially the base data was converted into raster format at 1 km resolution and subsequently this grid was converted into a point dataset. In this project a list consisting of 330.490 globally distributed coral reef point locations was used. Each record represents one single reef location with its geographic position (longitude/latitude) and a location code attached to it. To be able to create region-based reports the primarily country based location code was modified resulting in 146 separate geographic regions. Another important enhancement was the correction of non-systematic spatial displacements of reef points in coastal areas when compared to the Digital Chart of the World and the nighttime lights dataset. Reef location points were shifted irregularly in all cardinal points resulting in reefs wrongly located 'upcountry'. Because of the irregular direction of these displacements manual adjustment was essential for the further use of the data.

3. METHODOLOGY AND RESULTS

In order to reach a global assessment of potential anthropogenic stress to coral reefs a Lights Proximity Index (LPI) was calculated, measuring the distance of coral reef sites to the chosen stressors and incorporating the stressor's intensity. The stressors included in the index calculation are distinguished out of the annual composite of satellite observed nighttime lights: (1) cities and towns, (2) gas flares, and (3) heavily lit fishing boats. With regard to [6] we act on the assumption that the potential threat on coral reefs is inversely

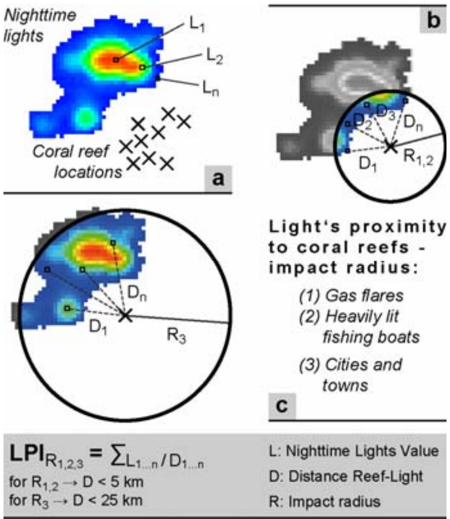

Figure 1. Concept of the Lights Proximity Index.

proportional to the distance of a reef location to an artificial night lighting source. This means that the nearer a coral reef is located to such a stressor the greater is the potential endangerment through direct and indirect impacts. The process was computed using interactive data language (IDL).

Fig. 1 visualizes the concept of the LPI. Starting point is a set of coral reefs in proximity to an area with artificial night lighting. During the LPI calculation a circle with a defined radius according to the respective reef stressor is computed around each coral reef location point. Only the lit pixels falling inside the circle area are used for the index calculation. As cities are considered to have a much larger influence the threshold value was set to 25 km (R_3) compared to a radius of 5 km used for reefs in proximity to gas flares and heavily lit fishing boats ($R_{1,2}$). The values of all relevant nighttime lights raster cells are summed up ($\Sigma_{L1...n}$) and divided by the sum of all distances from the coral reef point location to each of the raster cells ($\Sigma_{D1...n}$). As an indicator for potential reef stress the index value increases (on a continuous numeric scale) with smaller distance values and stronger nighttime lights.

The script calculating the LPI was run separately for each of the reef stressors with the analysis of the proximity of human settlements to coral reefs being most time consuming. The computation time for the fishing boats and gas flares LPI could be decreased considerably not only due to the smaller radius of the calculation circle but also because of the geographically limited occurrence of these lighting sources. The output of the three LPI computation runs was three ENVI raster files with corresponding text files for each of the reef stressors. The text files are identical to the original reef data list with the calculated LPI values as additional entry. The raster files are based on these text files having the index value of every single point location assigned to individual grid cells with one square kilometer resolution. The complete list of reefs and associated LPI values is available for download on the NOAA/NGDC web page (http://ngdc.noaa.gov/dmsp/download.html).

For visualization colorized LPI maps were created indicating the potential risk exposure of coral reefs worldwide. To describe the regional status of the influence of artificial night lighting and associated stressors on coral reefs and to be able to make inter-regional comparisons several rankings were created based on the previously adapted location code. To account for the variation in spatial extent and number of related reef points and thus to allow a comparison of differently sized reef systems, average LPI values were calculated for each region. Singapore stands on top of the list regarding impacts of human settlements featuring a small but highly stressed reef area – an assessment confirmed by local monitoring [8]. The coral reefs in the Persian Gulf (i.e. Bahrain, Iran, Qatar) turn out to be most affected by gas flaring. The area at highest risk from fishing boat activities is the Gulf of Thailand.

4. CONCLUSION AND OUTLOOK

Several regions feature a coincidence of multiple stressors that can eventually result in multiplicative negative impacts on the related coral reefs [1]. Further research should be done in this field, i.e. regarding the joint occurrence of human settlements and fishing boat activities in close proximity to reefs in the Gulf of Thailand. The results of the presented approach indicate that reefs in Puerto Rico, the Red Sea and the Persian Gulf are at highest risk from direct and indirect impacts of human settlements. We have used artificial lighting as a proxy measure for development and human activity. The results also indicate which reefs are likely subjected to unusually high levels of artificial sky brightness, a condition which has only recently been recognized as a stressor on reef organisms. The identification of areas subjected to artificial night lighting should raise awareness and lead to further investigations in that field. It can also be useful for identifying sites requiring restoration and precautionary actions. Regarding the LPI approach the next step is to create a time series and analyze temporal trends in human activity close to coral reefs.

5. REFERENCES

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