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

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ABSTRACT

In this paper a remote sensing based approach to assess potential anthropogenic stress to coral reefs worldwide is presented. Three reef stressors are analyzed using nighttime lights data derived from the Defense Meteorological Satellite Program (DMSP) produced at the National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center (NGDC). Artificial night lighting is an excellent proxy measure for associated human-caused stress. A growing body of evidence indicates that artificial sky brightness is a stressor for many reef organisms. 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.

Index Terms— DMSP, coral reefs, artificial night lighting, lights proximity index, anthropogenic stress

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. NOAA’s Coral Reef Watch has established a global sea surface temperature (SST) tracking system based on meteorological satellite data. The system automatically detects prolonged periods of high SST in coral reef locations and issues corresponding coral bleaching alerts. The use of high spatial resolution multispectral satellite imagery also enables detection of coral bleaching events as demonstrated in [4]. To date there has only been one single global survey of anthropogenic stress on coral reefs categorizing potential human impact and resulting in a set of risk classes (‘Reefs at risk’ [5]). Another integrated analysis of socioeconomic and environmental factors identifies human activities as key drivers of change in reef communities in the Caribbean [6].

In this paper a remote sensing approach based on DMSP nighttime lights is presented analyzing three anthropogenic activities known to have adverse effects on coral reefs. We use nighttime lights data as a proxy measure for indirect impacts on coral reefs like human associated chronic water pollution. In addition, artificial night lighting can have direct ecological consequences [7] like disrupted spawning and forage cycles.

2. DATA

2.1. DMSP nighttime lights

The DMSP Operational Linescan System (OLS) was initially designed to monitor the global distribution of clouds using visible and thermal infrared spectral bands. The DMSP satellites are in a sun-synchronous, low altitude polar orbit. With 14 orbits collected per day and a 3,000 km swath width, each OLS is capable of collecting a complete set of images of the earth every 24 hours. At night the visible band signal is intensified with a photomultiplier tube (PMT) to enable the detection of moonlit clouds. The boost in gain enables the unique capability of observing lights present at the earth’s surface at night. Most of the lights are from human settlements [8] and ephemeral fires [9]. Furthermore gas flares and offshore platforms as well as heavily lit fishing boats can be identified.

NOAA/NGDC archives the long-term DMSP data from 1992 to present. For this project individual orbits were processed with automatic algorithms (described in [8] and [10]) identifying image features (such as lights and clouds)
and quality of the nighttime data. A cloud-free composite of nighttime lights was produced for 2003 using data from DMSP satellite F-15 (see figure 1).

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 1 km² at the equator. In order to estimate the frequency with which lighting was present the total number of coverages and number of cloud-free coverages are tallied. The nighttime lights product used in the presented analysis is the average digital number in the visible band of cloud-free light detections multiplied by the percent frequency of detection. The inclusion of the percent frequency of detection term normalizes the resulting digital values for variations in the persistence of flaring. For instance the value for a gas flare only detected half the time is discounted by 50 %. 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 cities, human settlements and lit facilities on land, (2) gas flares, and (3) heavily lit fishing boats.

2.2. Coral reef data

The second database used in this project is a global spatial compilation of coral reefs. The data was obtained from ‘Reefs at Risk’ [5] 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 (see figure 2).

The location code in the original data assigned each reef point to a country. To be able to create region-based reports this location code was modified resulting in 146 separate geographic regions. In doing so the country-based structure was primarily kept and enhanced. Several input location codes were merged, others had to be split.

Another important enhancement of the dataset was the correction of non-systematic spatial displacements of reef points in coastal areas when compared to the Digital Chart of the World (DCW) 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

In order to reach a global assessment of the potential anthropogenic stress to coral reefs a Lights Proximity Index (LPI) was calculated, measuring the distance of coral reef sites to three 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] and [7] we act on the assumption that the potential threat on coral reefs is inversely 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). Figure 3 visualizes the concept of the LPI. Starting point is a set of coral reefs in proximity to an area with artificial night lighting (a). 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 and towns are considered to have a much larger influence the threshold value was set to 25 km (R₁ in part c) compared to a radius of 5 km used for reefs in proximity to gas flares and heavily lit fishing boats (R₁₂ in part b).

The values of all relevant nighttime lights raster cells are summed up (Σ₀₁…₀ₐ) and divided by the sum of all distances from the coral reef point location to each of the raster cells (Σ₀₁…₀ₐ). As an indicator for potential reef endangerment 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 computation analyzing the proximity of human settlements to coral reefs being most time consuming. Because of the global distribution of city lights all reef points had to be included in this calculation. The computation time for the fishing boats LPI could be decreased considerably because of the geographically limited occurrence of these lighting sources (Southeast Asia). Just those reef points located in the geographic region where heavily lit fishing boats had been detected in the pre-analysis of the nighttime lights data were included in the LPI calculation. The second factor reducing computation time is the smaller radius of the calculation circle.

The LPI script for gas flares was enhanced similarly. Several rather small regions featuring gas flaring are widely distributed over the whole globe. So the list of global reef location points was reduced to a list including all potentially affected reef areas in proximity to gas flares.

4. RESULTS

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 (longitude, latitude, location code) 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/EOG web page (http://ngdc.noaa.gov/dmsp/download.html).

For visualization colorized LPI maps were created. A modified rainbow color ramp indicates the potential risk exposure of the coral reefs starting with white which stands for no risk (LPI = 0 → no artificial night lighting source in close proximity) and turning via blue for low risk to green, yellow and finally red for high risk. The nighttime lights data can be displayed in the background as reference and a land-sea-mask is used for better orientation. Figure 4 shows the island of Puerto Rico as an example for a geographic region with coral reefs being highly endangered by human settlements. Particularly reefs along the north coast, near the capital San Juan, feature very high LPI values and are therefore characteristically displayed in red.

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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 a ranking was created based on the previously adapted location code. The geographic areas do not all have the same spatial extent and accordingly the number of related reef points varies significantly. To account for this variation normalized lists were created specifying the average LPI value for each region. This allows a risk exposure
comparison of big areas to smaller areas or general of areas with differently sized reef systems.

Table 1 shows the top five of the list regarding human settlements as the base stressor for the LPI calculation. The display of the average index values enables the comparison of a huge geographic region like Puerto Rico (2,626 reef points) with small regions like Singapore (61 points) and Israel/Jordan (16 points). Singapore stands on top of the list featuring a small but highly stressed reef area – an assessment confirmed by local monitoring [11].

As already described, according to the spatially limited occurrence of gas flares and heavily lit fishing boats only a reduced number of coral reef points had been used for the LPI calculation regarding these two stressors. Rectangular ‘calculation areas’ serve as a mask for selecting the relevant points. At its borders the predefined geographic regions and corresponding reef point clusters are dissected. Just those points located inside the calculation area are thus included in the index computation.

The geographic regions are the basis for the ranking lists and just considering a portion of the points for the calculation of the average LPI results in distorted values. By reassigning the full number of points to initially dissected areas the region rankings are corrected. Oman for example has just 12 of its 615 reef points located inside the ‘flares calculation area’. Just considering those 12 extremely high valued points for the calculation of the average index value would misleadingly lift Oman to the top of the ‘flares ranking’. Building the average of all 615 points restores the comparability.

After remerging all dissected region point clouds the coral reefs of Bahrain turn out to be most affected by gas flaring. With Iran, Qatar and the United Arab Emirates three more states of the Persian Gulf are in the top five of the list which is rounded off by Southeast Asia’s Brunei. The area at highest risk from fishing boat activities is the Gulf of Thailand followed by China, Vietnam and Taiwan.

5. DISCUSSION

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 for example regarding the joint occurrence of human settlements and fishing boat activities in close proximity to reefs in the Gulf of Thailand or the concurrence of gas flaring and strong lights from human settlements near coral reefs in the Persian Gulf.

Of course also relatively undisturbed, pristine reef areas exist. The Great Barrier Reef for example stands on the lower end of the ranking in this context. However, it is clear that there are other additional factors influencing the overall conditions of coral reef ecosystems [6]. Extensive research is already done in the field of analyzing changing sea surface temperatures resulting in coral bleaching events [4].

6. CONCLUSION AND OUTLOOK

In this paper a satellite based approach to gather information about the global coral reef exposure to anthropogenic stress was presented. Based on DMSP nighttime lights three reef stressors are analyzed by calculating a lights proximity index. The results 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. The last two regions are also greatly affected by gas flaring while fishing activities pose the greatest threat in the Gulf of Thailand.

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.

7. REFERENCES