FAO Fisheries and Aquaculture Circular No. 1057 FIRF/C1057 (En)

ISSN 2070-6065

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ESTIMATING REEF HABITAT COVERAGE SUITABLE FOR THE HUMPHEAD WRASSE, *CHEILINUS UNDULATUS*, USING REMOTE SENSING

by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2010

ISBN 978-92-5-106621-8

PREPARATION OF THIS DOCUMENT

The Napoleon fish (humphead wrasse) was listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II in 2004. Following listing, different efforts were directed towards developing approaches to assist range States in addressing CITES non-detriment finding requirements. In 2007 FAO published Fisheries Circular No. 1023 which elaborated a stock assessment method for estimating sustainable catch levels for the species in areas where estimates of reef area and fish densities are available. The lack of accurate estimates of reef areas suitable for the species was recognized as an important source of uncertainty for using the method in many range States. In view of this and of recent developments in the use of remote sensing techniques in mapping shallow water coral reefs, this study was commissioned to evaluate whether reliable estimates of humphead wrasse habitat coverage could be obtained using available satellite images. This study was funded by FAO regular programme and by the FAO Trust Fund Project (GCP/INT/987/JPN) "*CITES and Commercially-exploited Aquatic Species, Including the Evaluation of Listing Proposals*".

Oddone, A., Onori, R., Carocci, F., Sadovy, Y., Suharti, S., Colin, P. L., and M. Vasconcellos.
Estimating reef habitat coverage suitable for the humphead wrasse, *Cheilinus undulatus*, using remote sensing.
FAO Fisheries and Aquaculture Circular. No. 1057. Rome, FAO. 2010. 27p.

ABSTRACT

This study evaluates the use of satellite images for mapping shallow reef areas and the habitat of humphead wrasse. A method for mapping the suitable habitat for adult humphead wrasse is developed based on the location of reef edges on available Landsat images and on the application of a buffer area around the edges, where the probability of finding adult humphead wrasse is highest according to Underwater Visual Survey (UVS) data. The method is used to estimate the habitat coverage of the species in Indonesia, Malaysia and Papua New Guinea, three of the most important exporting countries of the species. The total estimated habitat coverage was 11 892 km^2 in Indonesia, 941 km^2 in Malaysia and 5 254 km^2 in Papua New Guinea. The estimates for Indonesia and Malaysia are approximately four times smaller than other available estimates of reef coverage for these countries, the difference being explained by the higher accuracy of the method used in the present study in identifying the location of shallow water fringing reefs. It is concluded that, for the purpose of estimating the suitable areas of humphead wrasse as a basis for defining population size and sustainable export quotas, the results obtained in the present study are more conservative and appropriate than previously available estimates of reef areas.

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1. INTRODUCTION

Global and regional estimates of coral reef areas are of considerable value in different fields, including fisheries assessment, marine conservation and environmental change. Despite this, the available estimates of reef areas vary substantially, partly due to divergences in the definition of reef habitats but also because of lack of information about reef coverage and of cost-effective methods of reef mapping.

An innovative method for reef mapping has been proposed involving the use of available (free) Landsat satellite images of coastal areas and Geographical Information Systems. This method, so far used to produce maps of geomorphological classes of reefs in selected areas of the world (Andrefouet *et al*., 2004), has the potential to be used in the assessment of the coverage of reef fish habitat. This information is particularly needed in the assessment of reef associated fish stocks in data-limited areas. In this study remote sensing techniques are used to evaluate the habitat coverage of the humphead wrasse, *Cheilinus undulatus*. However, the method is expected to be widely applied to other tropical fish stock assessments and to influence the design of marine protected areas and other spatial measures for marine ecosystems conservation.

The humphead wrasse, *Cheilinus undulatus*, is the largest living member of the Labridae family, with a maximum size exceeding two metres and 190 kg (Sadovy *et al*., 2003). Its geographic range covers much of the Indo-Pacific. The species is not common, recorded maximum adult densities rarely exceeding 20 fish/10 000 m^2 and usually at least half this density (Sadovy *et al*., 2003). Small individuals are typically associated with high coral cover; larger fish are found singly or in small groups mainly on outer or deep reefs, seagrasses, steep slopes and passes, where they also spawn.

Humphead wrasse is a small but important part of the overall trade in live reef food fish. Although the fish is not even close to being the most important species in terms of volume in the China–Hong Kong Special Administrative Region (SAR) market, it is one of the highest in unit value. The total recorded international live trade in this species ranged from about 58 to 138 tonnes for the years 2000–2006. Although humphead wrasse occurs in the waters of 48 countries, the important suppliers of this fish to live trade are limited to a few countries in Southeast Asia and Papua New Guinea where a major percentage of their coral reef habitat occurs. In addition to its role in the live reef food fish trade, the humphead wrasse is valued for several reasons, especially for local food and for its role in dive tourism (Gillett, 2010).

The humphead wrasse was the first coral reef fish to be listed on CITES Appendix II (2004). Before issuing an export permit for a CITES Appendix II species, exporting countries must determine whether the volume of export will be detrimental to the survival of the species in the wild. A Non-Detriment Finding (NDF) requirement is therefore needed for countries exporting humphead wrasse. This requirement involves several facets, including a scientific basis for the level of removals. To this end Sadovy *et al*. (2007) developed a stock assessment approach for the humphead wrasse where an age-, sex- and size-structured population model is used to estimate an “optimal” exploitation rate for the species. Model outputs are combined with estimates of population densities, obtained from Underwater Visual Surveys (UVS), habitat size and fish removals (legal and illegal) to calculate a sustainable level of export. One of the key points of information needed in the approach is an estimate of the habitat area of the species, which is used to estimate population size from site-specific densities.

The objective of this study was first to evaluate whether remote sensing techniques could be used to provide a precise and cost-effective means of estimating the area coverage of shallow coral reefs. The second objective was to determine a methodology that enables the use of available satellite imagery and field data to estimate the coverage of reef areas suitable for the humphead wrasse. The methodology developed is finally used to estimate the approximate total area of coral reef habitat suitable for humphead wrasse in Indonesia, Malaysia and Papua New Guinea, three of the most important exporting countries of the species.

1.1 Applicability of satellite images to the mapping of coral reefs

The launch of the Landsat 1 satellite on 23 July 1972 opened the era of commercial Earth Observation. Since that year many different satellites, originating from different countries and carrying different sensors, began populating the sky and continuously monitoring the planet. Yet each satellite is unique in the characteristics of its sensors, built to satisfy certain specific applications. In this regard commercial satellites can be divided into four classes:

1. optical low resolution satellites
2. optical medium resolution satellites
3. optical high resolution satellites
4. radar satellites, with low to medium resolution

For the purposes of this study the radar sensors were not suitable, as their signals are not able to penetrate the water to allow the identification of reef areas, even though they have the great advantage of imaging through clouds, a continuous presence in tropical areas.

Optical low resolution satellites are generally equipped with multi-band sensors, yet their low resolution (in the range of 500–1 000 metres) does not give the required detail needed to define the habitat of a reef fish. High resolution satellites (2.5 to 0.6 metre resolution), on the other hand, are probably the best source of information, but their very small coverage (max 16.5 x 16.5 km images) in addition to their high cost make them an impractical solution for the mapping of large areas.

The best solution is to use medium resolution optical satellites, with a resolution in the range of 10–30 metres. Unfortunately almost all the satellites in this class are mainly designed for land applications (especially agriculture) and therefore have sensors designed to look more into the Near-Infrared range (0.75 to 1.4 micrometers) than into the visible range (0.38 to 0.75 micrometres), thus reducing their suitability for sea applications. As a matter of fact the French SPOT constellation, the Indian IRS constellation, the English DMC and the Japanese Terra/Aster sensors do not have a Blue band in their multispectral sensors, eliminating the ability to read information from water bodies. Figure 1 demonstrates how water reflection is almost zero in the Near-Infrared range, where vegetation has its peak of reflection.

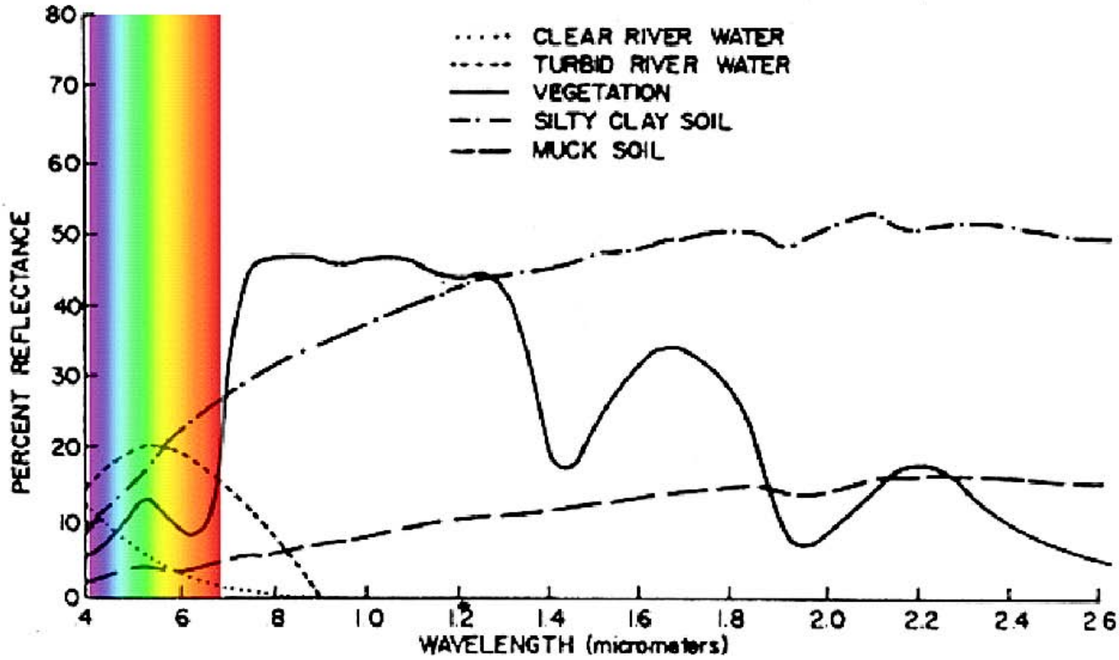

Figure 1: Examples of spectral signatures of different objects, i.e. the percentage of sun energy reflected at the different wavelengths of the electromagnetic spectrum (*modified from:* www.fao.org/docrep/003/W0615E/W0615E21.gif).

There is only one medium resolution mission that has always carried a sensor that can read information from the Blue band, and this is the long-running US Landsat project. This satellite has been the major source of satellite-based reef classifications in recent years, and although the two active satellites (Landsat 5 and Landsat 7) are facing some technical problems, they will continue to be the major source of detailed information from water bodies for many years to come.

It is expected that the ability to use satellite images to map coral reefs and other aquatic habitats and features will improve in the near future with the launching of new sensors. In particular the launch of new high resolution sensors with increased agility and higher acquisition rates (e.g. WorldView-2, launched in 2009, with an eight-band Multispectral sensor including a dedicated "Coastal band" in the range of 420–450 nm) will reduce the impact of their small swaths. In the next few years there will also be new medium resolution satellites (with Blue bands), including the English Rapid Eye constellation of four satellites at 6.5 metre resolution that will allow a daily revisit and the ESA's Sentinel 2 constellation, that will guarantee a 5-day continuous monitoring of the whole Earth with a resolution up to 10 metres.

1.2 Some technical details of Landsat satellites

Landsat satellites have been operative since 1972, and at present there are two working satellites: Landsat 5, launched in 1984 and carrying the Thematic Mapper (TM) sensor, and Landsat 7, launched in 1999 and carrying an Enhanced version of the same sensor (ETM+). Both satellites are able to provide a 30-metre resolution multispectral image of the Earth every 16 days, covering a swath of about 180 km (Table 1).

Table 1: Technical details about the different sensors onboard the Landsat 5 and Landsat 7 satellites.

Band number	**Band type**	**Spectral range (µm)**	**TM (resolution m)**	**ETM+ (resolution m)**
1	Blue	0.45–0.52	30	30
2	Green	0.52–0.60	30	30
3	Red	0.63–0.69	30	30
4	NIR	0.76–0.90	30	30
5	NIR	1.55–1.75	30	30
6	TIR	10.42–12.50	120	60 (*)
7	SWIR	2.08–2.35	30	30
8	PAN	0.52–0.90		15

(*) = available in both High and Low gain

Unfortunately on 31 May 2003 the Landsat 7 experienced a major instrument anomaly (failure of the instrument's scan line corrector, SLC), and as a result is no longer operational. For this reason the old Landsat 5 is now the main source of data, and even if it has a reduced functionality due to some problems with the solar panels and a partial degradation of the sensor, after 23 years of activity it is still acquired by many stations all over the world. Note that Landsat 7 has an on-board memory that allows it to acquire images everywhere in the world through the United States Geological Survey (USGS) long-term acquisition plan, while Landsat 5 has no on-board memory and therefore is dependent on the availability of a receiving station, which means that it can only acquire images over the footprints of the available receiving stations (Figure 2).

In 1998 NASA decided to create a set of the best Landsat TM and MSS (Multispectral Scanner System) images available on a world-wide basis, and to make it available to the research community for free. This TM and MSS dataset has also been integrated with Landsat 7 ETM+ world coverage, created using images acquired around the year 2000, with the lowest possible cloud cover and geo-referenced with an error of about 50 m.

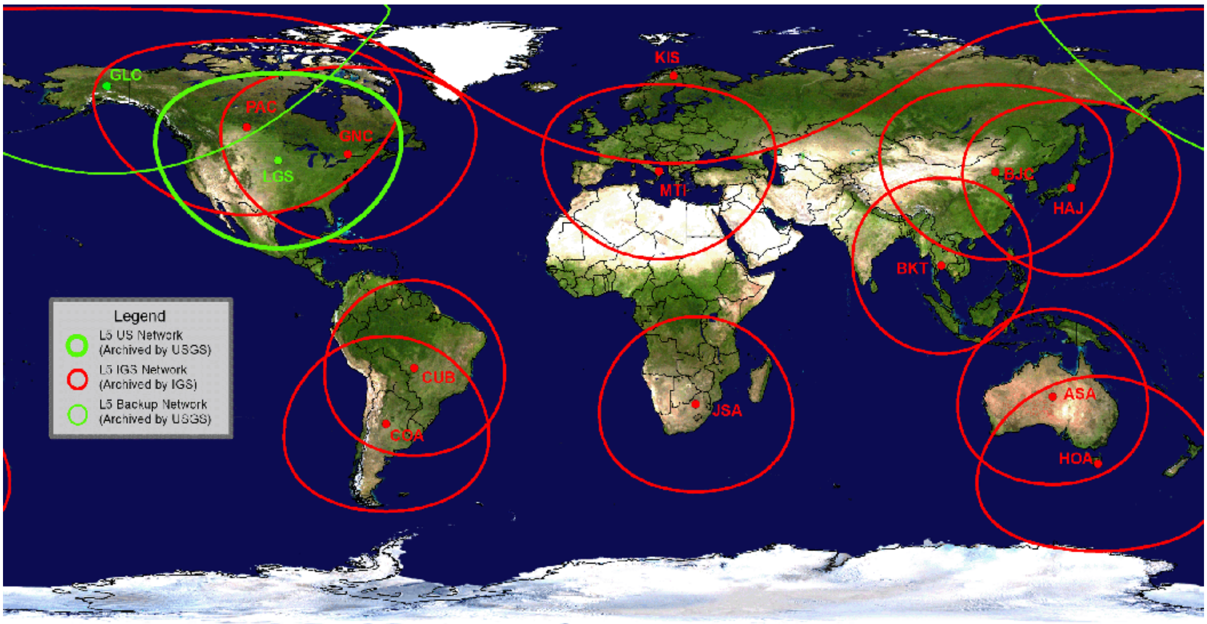

Figure 2: Map showing the extension of the footprints of the Landsat 5 receiving stations presently active all over the world (http://landsat.usgs.gov/about_ground_stations.php).

By using a consistent dataset of these multispectral Landsat 7 images acquired between 1999 and 2003, the Institute for Marine Remote Sensing at the University of South Florida is developing the first global uniform map of shallow coral reef ecosystems. This initiative, called Millennium Coral Reef Program, aims to highlight similarities and differences between reef structures on a scale never before considered by traditional work based on field studies (Sadovy, 2005). The project has included an unprecedented standardization of geomorphological structures for reefs around the world. The goal of the Program is "to provide a reliable, spatially constrained data set for biogeochemical budgets, biodiversity assessment, reef structure comparisons and also new high-quality information for reef managers about reef location, distribution and extent". One limitation of the program with regard to the objectives of the present study is that it provides vector maps of geomorphological coral reef structures which are of little use in defining the reef habitat for humphead wrasse.