

2. METHODOLOGY

The present study consisted of two phases. First a test study was conducted to evaluate whether Landsat 7 images could be used to identify the habitat of humphead wrasse in Indonesia. To perform this study a set of satellite images was collected for six areas in Indonesia that have been surveyed for humphead wrasse using UVS (Figure 3, Sadovy, 2005). The second phase of the study applied the methodology developed in the test phase to calculate the suitable habitat areas for humphead wrasse in Indonesia, Papua New Guinea and Malaysia.

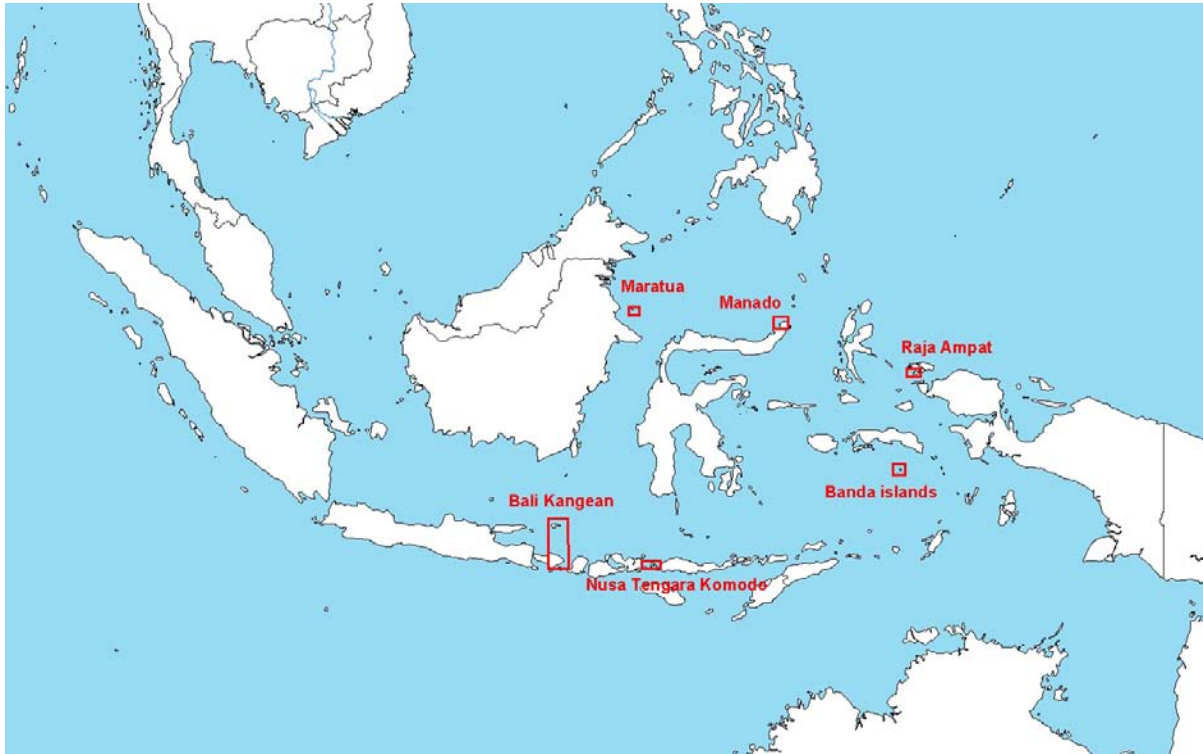


Figure 3: Map showing the extension of the six surveyed areas in Indonesia analysed in this study.

To perform the initial study, all the Landsat 7 images available in the Millennium Coral Reef website (<http://oceancolor.gsfc.nasa.gov/cgi/landsat.pl>) over the six surveyed areas were downloaded. In total twelve Landsat 7 images were used (Table 2 and Figure 4). Every Landsat image is identified by three numbers that define it in a unique way:

- Track: this number refers to the satellite orbit and can be generalized as the “longitude” of the image.
- Frame: this number represents the reference scene along the orbit and can be generalized as the “latitude” of the image.
- Acquisition date: the obvious parameter that differentiates all the Landsat scenes acquired over the same area (i.e. same track and frame).

The Landsat images were imported into the ERDAS Imagine format, a format which allows a quick display thanks to the pyramid layer approach and which is fully compatible with ESRI ArcGIS, which was the main software used for this study.

Of the eight available bands (see Table 1) only four were imported and used in this study because of their suitability to the analysis of sea spaces: blue (1), green (2), red (3) and near infrared (4) bands. The images were generally displayed with a Natural Colour combination (RGB = 321) or with a False Infrared combination (RGB = 432) (Figures 5 and 6).

Table 2: List of the 12 Landsat 7 scenes used over the six surveyed areas. In the Banda Islands survey area there are two Landsat 7 scenes on the same track/frame (107-63). This is due to the fact that there were no cloud free images available, and therefore NASA provided the two best acquisitions available.

Track number	Frame number	Acquisition date
Test area: Bali Kangeam		
116	65	19 August 2000
116	66	19 August 2000
117	65	9 September 1999
Test area: Banda Islands		
107	63	6 July 2001
107	63	26 October 2001
108	63	11 August 2000
Test area: Manado		
111	59	18 July 2001
112	59	20 April 2001
Test area: Maratua		
116	58	6 August 2001
116	59	15 May 2000
Test area: Nusa Tenggara Komodo		
114	66	20 July 2000
Test area: Raja Ampat		
108	60	26 September 1999

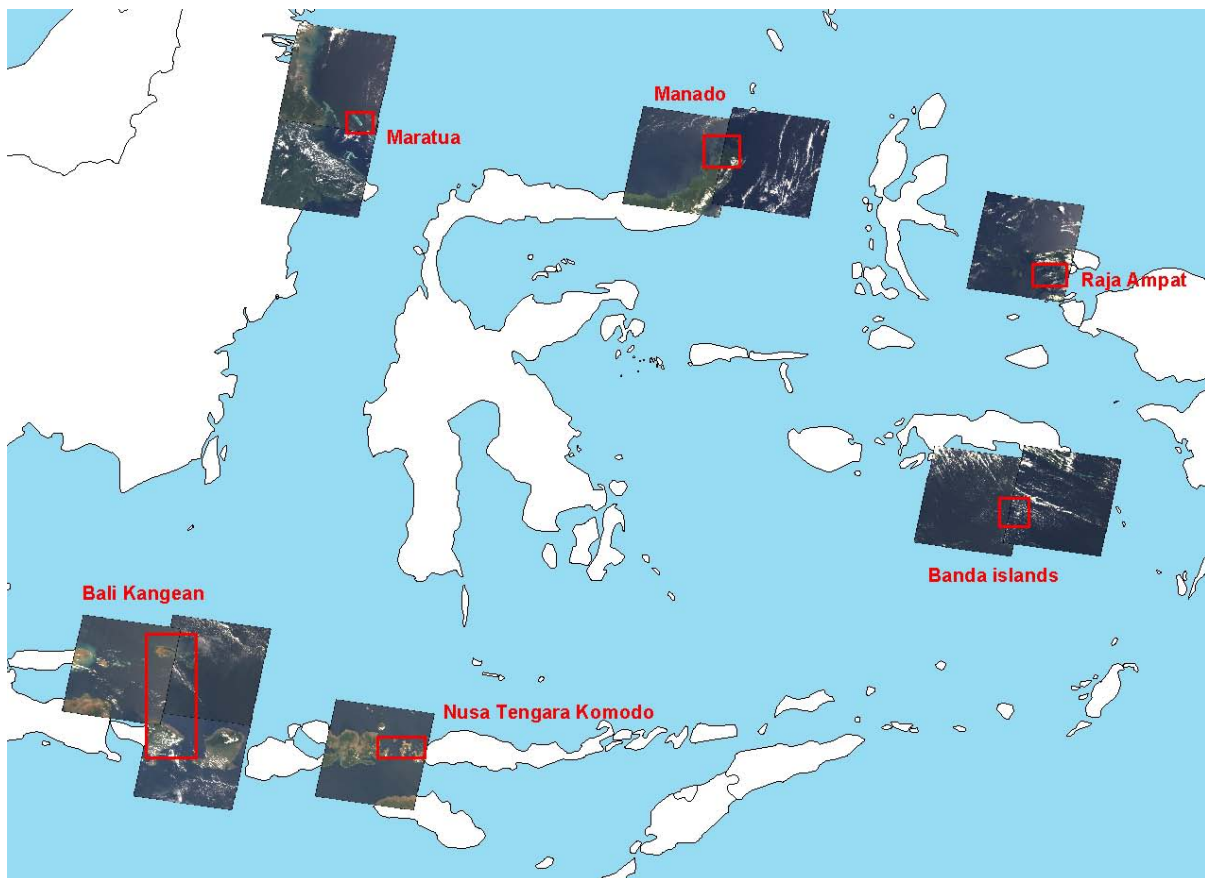


Figure 4: Map showing the 12 Landsat 7 scenes and the extension of the six test areas.



Figure 5: Landsat 7 image over the Maratua atoll displayed with a Natural Colour (RGB=321) band combination.



Figure 6: Landsat 7 image over the Maratua atoll displayed with a False InfraRed Colour (RGB=432) band combination; under this colour combination the vegetation becomes red because of the high reflection in the infrared range.

For comparative purposes, two other types of satellite images were obtained over the Maratua area: a SPOT-2 and a QuickBird scene (Figures 7 and 8 respectively). The SPOT-2 scene (provided by courtesy of SpotImage) was acquired on 17 July 2001 and is composed of three bands (green, red and near infrared) with 20 metre resolution. The QuickBird scene (provided courtesy of DigitalGlobe) was

acquired on 8 December 2006 and is composed of two images: a Panchromatic image at 60 cm resolution and a four-band (blue, green, red and near infrared) multispectral image at 2.4 metre resolution. The geolocation accuracy of this product (Standard Ortho-Ready processing) is 23 metres (circular error, CE 90%). Using the algorithm created by Dr. Yun Zhang of the University of New Brunswick (available using PCI software), the two QuickBird images were merged creating a four-band pan-sharpened product at 60 cm resolution. All the SPOT and QuickBird images were also imported into the ERDAS Imagine format.

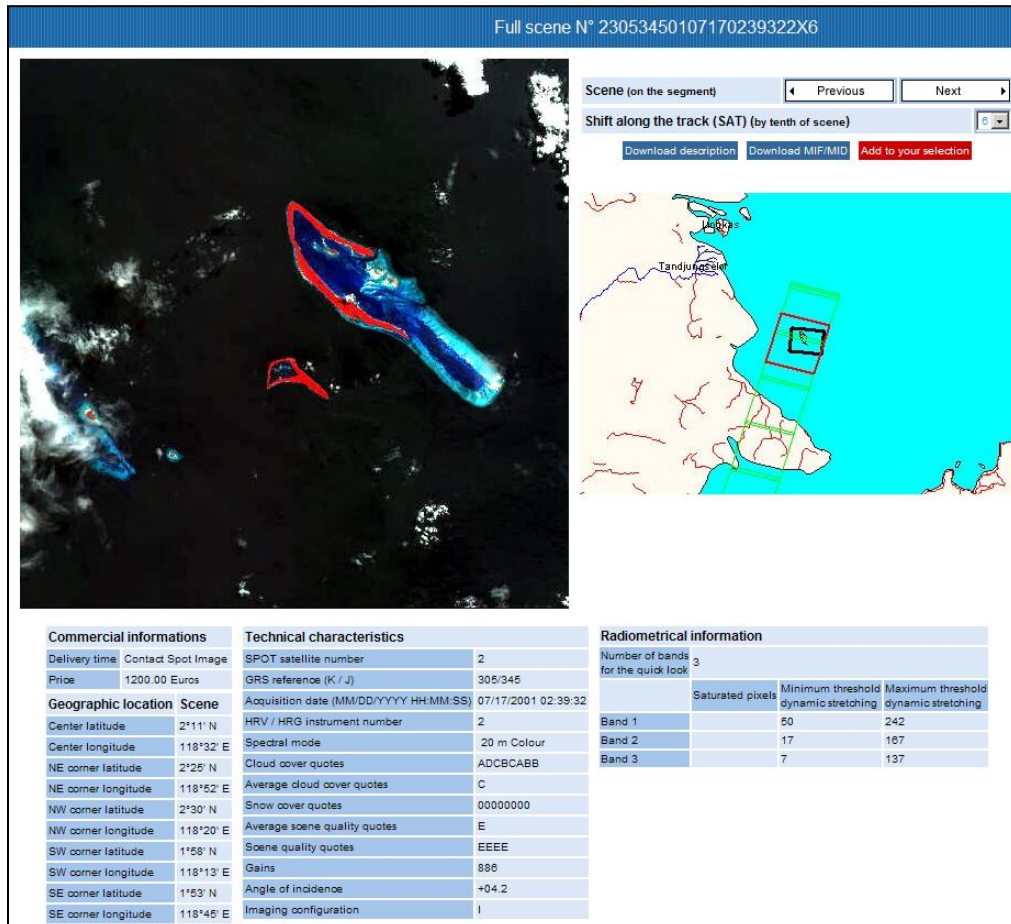


Figure 7: Technical details of the SPOT-2 satellite image of the Maratua area.

2.1 Ground surveys in Indonesia

Between 2005 and 2006 UVS were conducted in six areas of Indonesia to estimate humphead wrasse densities in areas with contrasting levels of fishing exploitation. The diving team used a floating GPS that allowed a detailed tracking of the diving paths (every 15 seconds the GPS systems recorded the position of the diver, with an expected accuracy of a dozen metres). All the GPS measured coordinates were transformed into Environmental Systems Research Institute, Inc. (ESRI) shape files, one for each survey area. The surveys were made in areas that showed all the typical aspects of the habitat of the humphead wrasse with a focus on adult habitat. Divers recorded the position of all humphead wrasse encountered during the surveys. Table 3 lists the dates of the surveys in each area and Figure 9 shows an example of a survey conducted in the Banda Islands.



Figure 8: QuickBird satellite image of the Maratua area.

2.2. Definition of the humphead wrasse habitat

Humphead wrasse is usually found in association with well-developed coral reefs (Sadovy *et al.*, 2003). Juveniles occur in coral-rich areas of lagoon reefs, particularly among live thickets of staghorn *Acropora* sp. corals, in seagrass beds, murky outer river areas with patch reefs, shallow sandy areas adjacent to coral reef lagoons and in mangrove and seagrass areas inshore. Fish tend to move into deeper waters as they grow older and larger. Adults are more common offshore than inshore; their preferred habitat being steep outer reef slopes, reef drop-offs, passes and tops, channel slopes, where they also reproduce, and lagoon reefs to a depth of at least 100 m. They are typically found in association with well-developed coral reefs and may be somewhat sedentary, i.e. the same individuals may be seen along the same stretch of reef for extended periods. Indeed, many commercial dive sites have their “resident” humphead wrasse, a favourite species for divers in many areas. Population densities are never high, even in preferred habitats. For example, in unfished or lightly fished areas, adult fish densities may range from 2 to 20 (but rarely >10) individuals per 10 000 m² of reef (Sadovy *et al.*, 2003). This is very low for a commercially targeted reef species and is more akin to densities of large terrestrial animals. In heavily fished areas, numbers can be up to ten times less than in unfished areas. In some countries the species has become rare due to overfishing (Sadovy *et al.*, 2003).



Figure 9: Example of ground survey in the Banda Islands area overlaid on a Landsat Natural Colour image; yellow dots represent the GPS measurements of the area inspected by the survey specialists, while the red dots are the humphead wrasse spotting registered.

Table 3: Transects and dates of the UVS conducted in the six areas.

Area	Number of transects	Date
Bali Kangeam	32	22–28 June 2005
Banda Islands	69	3–8 October 2006
Manado	40	15–17, 19–21 and 23–25 July 2005
Maratua	61	22–24 and 26–27 September 2006
Nusa Tenggara Komodo	33	6–11 April 2006
Raja Ampat	23	18–25 November 2005

Different attempts were made to automatically classify the fish habitat in the Landsat images. Using ESRI ArcGIS Image Analyst functions the images were classified using quantile and standard deviation breaks, cell statistics and slopes. In many cases, by fine-tuning the parameters, it was possible to identify the reef areas. However, because many other features in the image gave the same classification results as the coral reefs, it was very difficult and time-consuming to perform the extraction of the coral reef class. The presence of clouds, cloud shadows and small water reflections on sparse waves are additional critical aspects for the classification that precluded the use of a pre-defined masking. For instance, through an automatic edge detection algorithm (Figure 10) it was possible to find the edge areas between “coral reef and land” and between “coral reef and sea”, but also a lot of other edges between different objects in the image, like clouds, shadows, different vegetation, shoreline, etc. Another limitation is that the automatic procedure needs to be fine-tuned to every single Landsat image, as each one has a different radiometry, different sea structures and different weather conditions. Therefore it was concluded that such an automatic classification procedure, even if possible, would be time-consuming and not beneficial in terms of costs. A similar conclusion was also reached by the Millennium Coral Reef project (Andrefouet *et al.*, 2004).

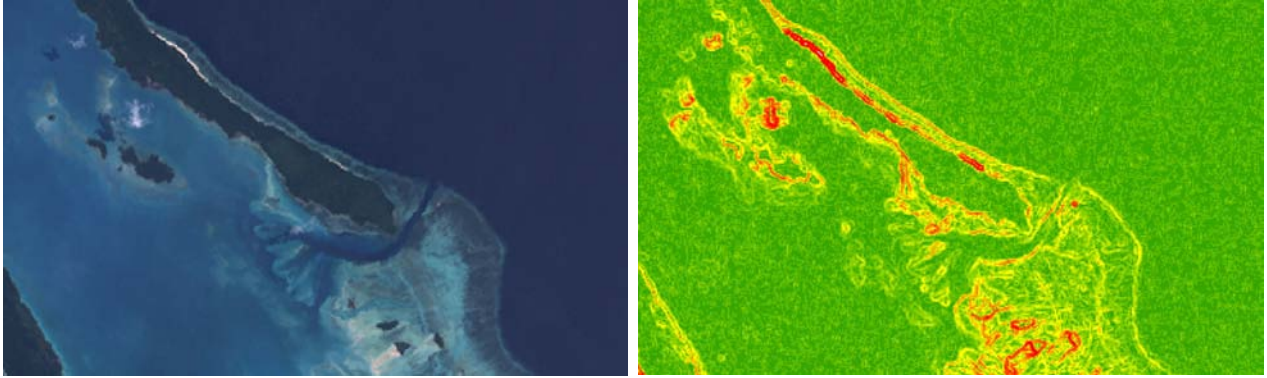


Figure 10: Example of an automatic slope definition of the Landsat image over Maratua atoll.

We also tried to use the GEOVIS and LCCS software developed by FAO's Africover project, but this did not give improved results and was more complicated to use and setup. Object-oriented classification software like eCognition may give better results, thanks to its ability to handle complex classification problems that require the consideration of local contextual information or other spatial data sets, but it has not been tried yet. Another practical method of assessing the habitat area of the humphead wrasse could be to use the maps of morphological reef types produced by the Millennium Coral Reef project, once they are completed (currently only a small area of Indonesia has been covered by the project).

Another important limitation in the use of Landsat images to assess the habitat area of humphead wrasse is that these images do not allow the identification of the external slope areas of the reefs, which is the common preferred habitat and spawning ground of adult humphead wrasse. Optical satellite images, even if they carry a multispectral sensor equipped with blue band, are not able to penetrate the water for more than five–six metres. For this reason they can be used to detect coral reefs only in shallow waters, but not in slope areas down to 100 m depths, where the fish is commonly found.

An empirical procedure was therefore used to map the habitat of the humphead wrasse. First, an operator manually draws the external borders of all the reef areas he is able to identify on the Landsat images (Annex 1 contains further information on basic procedure used to identify reef areas). Second, a fixed buffer zone is applied on both sides of the reef slope margins, thus including part of the reef habitat of young fishes, and the slope areas, habitat of adult fishes (Figure 11). The habitat extension is therefore calculated based on the area of the polygon formed by the buffer zone.

Potential sources of errors with the approach relate to the georeferencing accuracy of the images and to the ability of the operator to distinguish between dead and live coral and reef areas in different sea conditions. It should also be mentioned that the Landsat images available and used were six–eight years old (from 1999 to 2001), which means that the results do not necessarily reflect the current conditions of the reefs.

2.3 Definition of buffer area

Figure 12 shows a schematic representation of a typical barrier reef section, indicating the reef edge and the buffer area. It has to be said that the reef edges detected on the Landsat images are in reality the lines where the reef disappears from the Landsat image into the deep sea. This is not the end of the coral reef, but only the area where the reef is becoming too deep to be seen on a Landsat image (on average at five to six metres depth). If it is considered that the reef drops into the ocean with a 45° slope, a 100 metre buffer would cover an area to a depth of 100 metres (the limit of humphead distribution) on the offshore face of the reef. The 100 metre buffer towards the inside reef would cover the low water reef area.



Figure 11: Example of identification and manual vectorialization of reef edges and automatic buffering on the reef edges in the Maratua atoll.

As can be seen in Figure 13, in some cases the 100 metre buffer can be too big for islands with narrow fringing reefs, while in others it can be too small and underestimate the actual extent of reef areas. However, overall a buffer area of 100 metres seems to best fit the different morphological types of fringing reefs in Indonesia. The definition of a more complex buffer (e.g. asymmetrical on the two sides of the reef edge or customized for every single area) would simply create a more difficult and time-consuming procedure, the effects of which would probably not be significant in the overall definition of the habitat area. It must also be remembered that 100 metres on a Landsat image are equivalent to three pixels, which is almost the visual limit of detection of objects in a Landsat image.

2.4 Habitat classification using SPOT and QuickBird images

SPOT imagery, even if lacking a Blue band, allows for a good differentiation between coral reef areas and land/sea (Figure 14). However, the SPOT images are not available as orthorectified products (like the Landsat ones) and therefore their accuracy is an additional problem to be considered when choosing such a source of reference images.

Despite the slightly higher resolution of SPOT images (20 metres) compared to Landsat images (30 metres) they do not offer a substantial advantage considering the higher price (minimum 1 200 Euro versus approximately 500 Euro for a new Landsat scene) and the smaller area covered per frame (nine times smaller than a Landsat frame).

The very high resolution of a QuickBird scene, on the other hand, offers a perfect tool to help an operator define the limits of coral reef areas with precision (Figure 15). Yet the high price and very small scene size of QuickBird images (less than 100 times smaller than a Landsat), make them impractical for mapping reefs in large areas of the ocean.

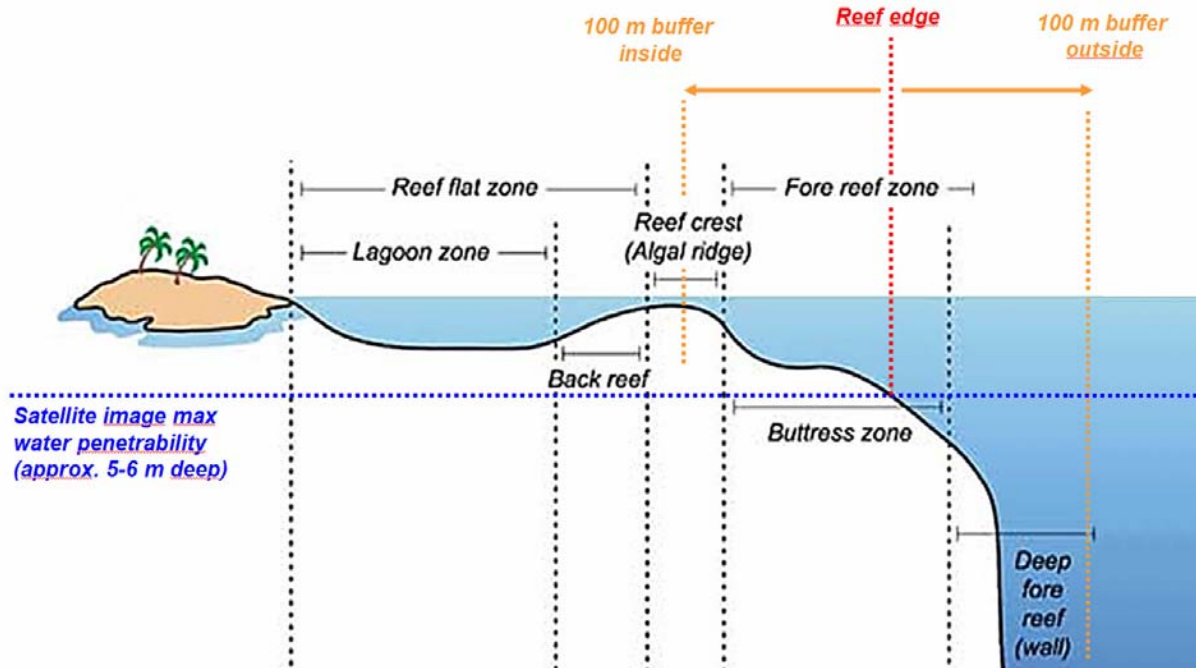


Figure 12: Section of barrier reef with indication of the reef edge and 100 metre buffer area (linear structures are not drawn to scale). In this example there is a steep reef wall, but this is not necessarily the norm.

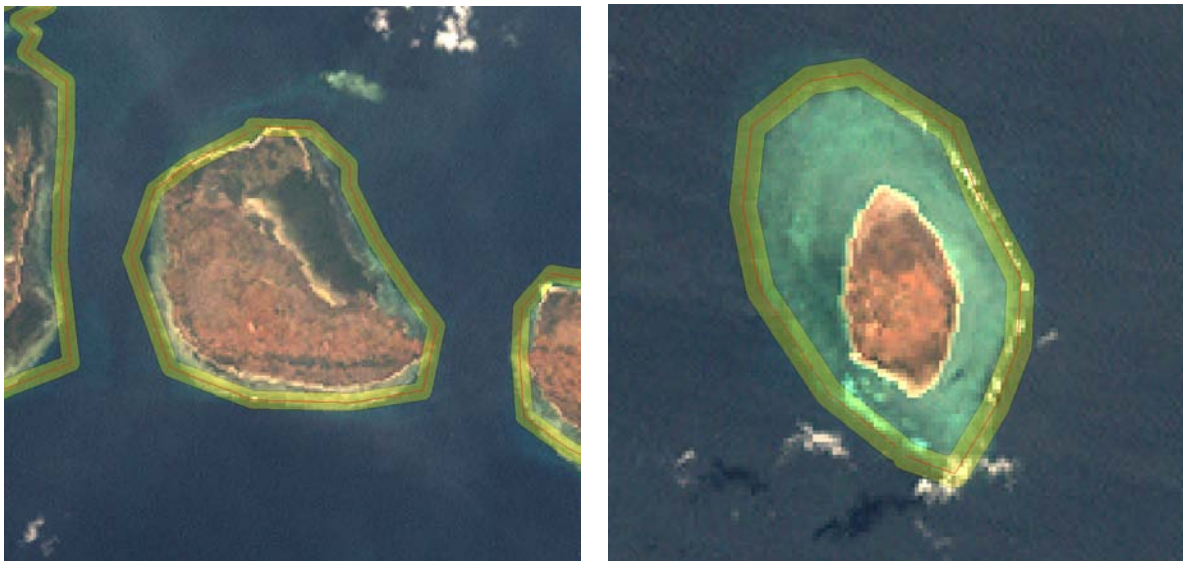


Figure 13: Example of situations where a 100 m buffer overestimates (left) and underestimates (right) the coral reef area.

2.5 Evaluation of humphead wrasse habitat at country level

Following the empirical procedure defined above, the next phase of the study was to calculate the suitable adult habitat areas in Indonesia, Malaysia and Papua New Guinea. To perform this work we used 279 Landsat 7 scenes covering the area of interest (Figure 16). The scenes were downloaded from the Reefbase database (<http://reefgis.reefbase.org/mapper.asp>) and from the Global Land Cover facility of the University of Maryland (<http://www.gcrmn.org>). All scenes were acquired between 1999 and 2002 (Annex 2). The missing scenes in the grid shown in Figure 16 are either completely over land or in the sea areas where no coral reefs were identified.



Figure 14: Overlay of the buffered habitat areas on the corresponding SPOT-2 satellite image, showing a shift due to the low geolocation accuracy of the SPOT image



Figure 15: Overlay of the buffered habitat areas on the corresponding QuickBird satellite image.

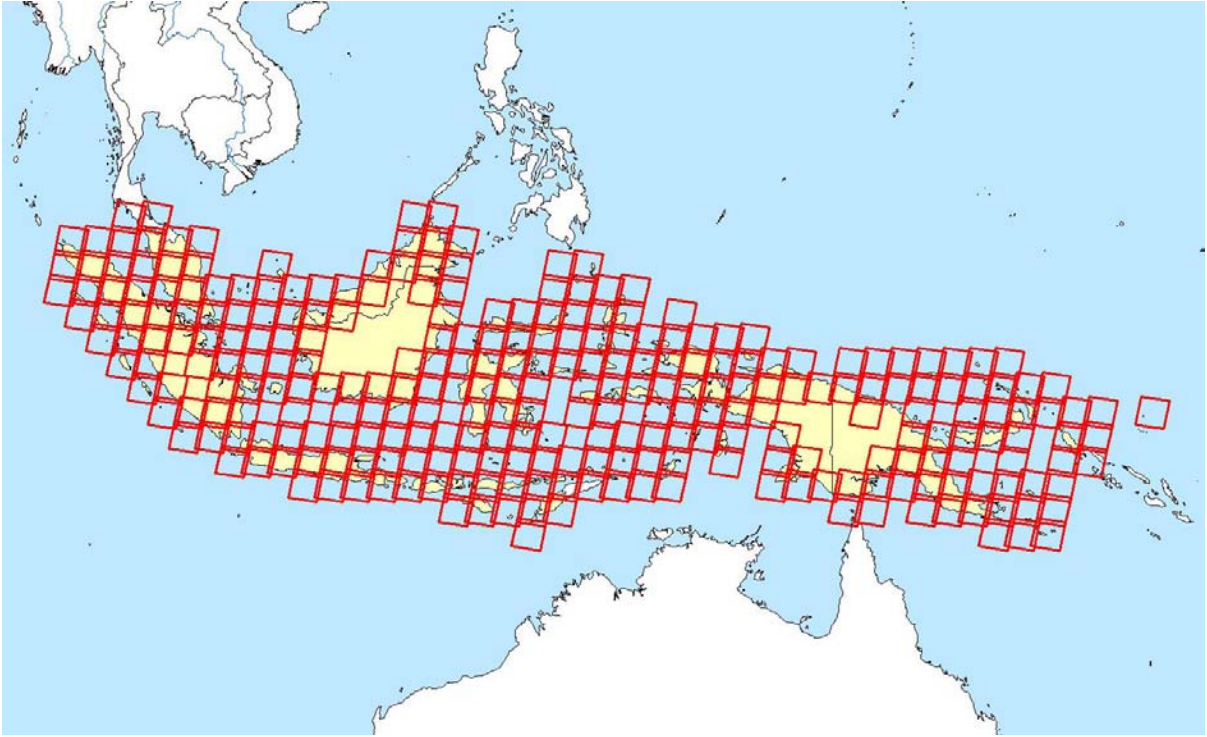


Figure 16: Grid of 279 Landsat 7 scenes used to calculate the humphead habitat areas in Indonesia, Malaysia and Papua New Guinea.