3. RESULTS AND DISCUSSION

The overlay of the habitat area defined by the reef edges and buffer zone with the actual location of humphead wrasse detected by the UVS in Indonesia indicated that overall the habitat areas accurately matched areas of fish occurrence (see example in Figure 17).

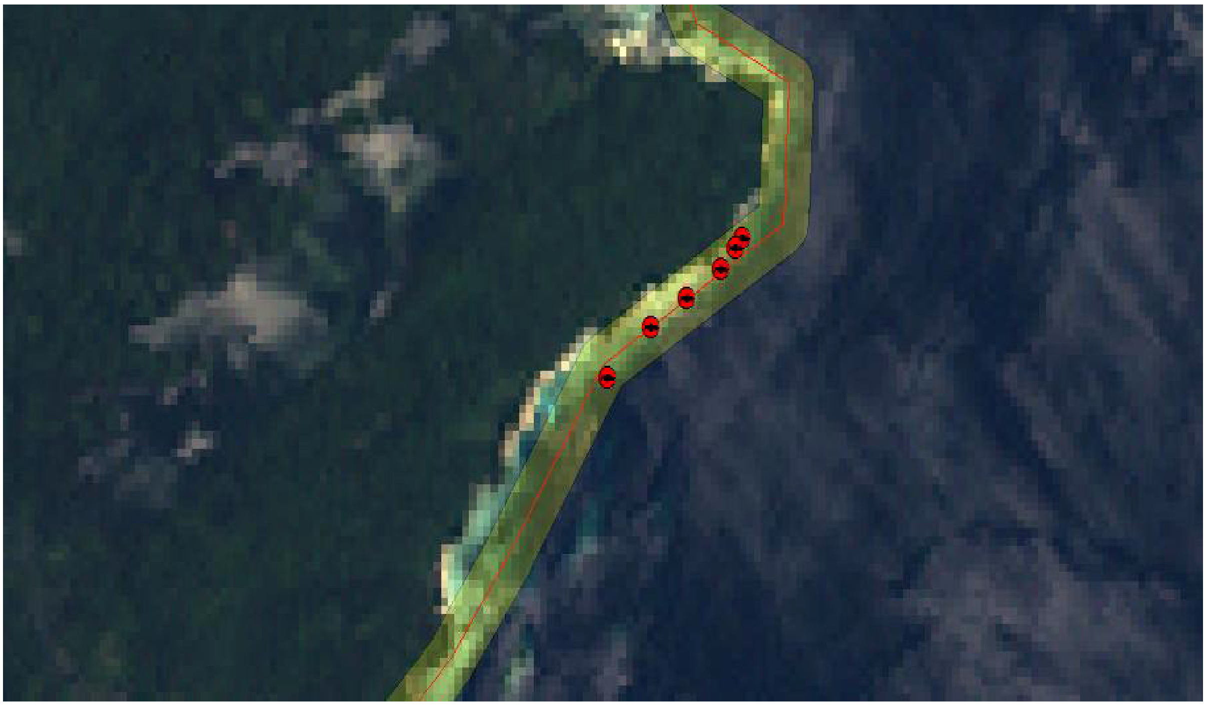

Figure 17: Example of habitat definition with humphead wrasse detected during the UVS in Indonesia.

Figure 18 and Table 4 show the position of 180 humphead wrasse detected during the surveys relative to the calculated position of reef edges. Results indicate that 96 percent of all the fishes are inside the 100 metre buffer zone. If the width of the buffer was reduced to 80 metres on each side of the reef edge the number of fishes inside the buffer zone would reduce to 92 percent. The accuracy of the method in determining humphead wrasse habitat can be deemed adequate, considering that only four fishes (2.2 percent of the total) were detected in areas that were not identified as reefs by the operator. Three of them were in areas where the resolution of the image did not allow the detection of reefs; the fourth was in an area covered with clouds.

The fishes detected were approximately symmetrically distributed around the reef edges (56 percent of the detected fishes were inshore and 44 percent offshore), indicating that the application of a symmetrical buffer (100 metres inside and outside the reef edges) was an adequate solution to the mapping of humphead wrasse habitat.

The total area of potential humphead wrasse habitat in the six test areas in Indonesia covered 838 km^2, distributed along 4 213 km of reef edges (Table 5).

Table 6 and Figures 19 to 21 show the results of the application of the method to Indonesia, Malaysia and Papua New Guinea. The total reef area suitable for humphead wrasse was 11 892 km^2 in Indonesia, 941 km^2 in Malaysia and 5 254 km^2 in Papua New Guinea. Previous estimates of reef areas were available only for Indonesia and Malaysia. Burke at al. (2002) estimated that the total reef areas in Indonesia covered 50 875 km^2 and in Malaysia 4 006 km^2. Both estimates are approximately four times larger than the habitat areas for humphead wrasse calculated in the present study for these countries. How can we reconcile these two independent results in view of the need to obtain accurate information about the humphead wrasse habitat area?

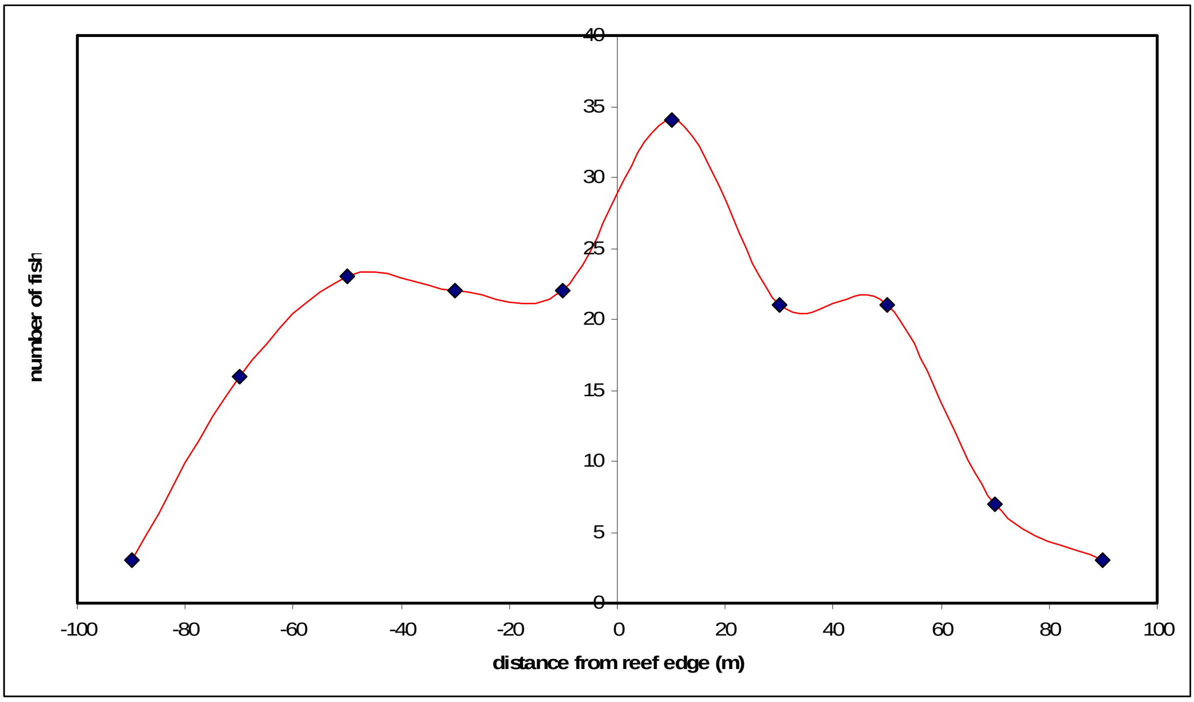

Figure 18: Distribution of humphead wrasse detected in UVS relative to the position of reef edge in the satellite images. A positive distance means that fish were located towards the open sea (slope area); a negative distance means that fish were detected in shallow reef areas.

Table 4: Position of humphead wrasse in buffer areas of different widths.

Distance from reef edge	Number of fishes towards the open sea	Number of fishes towards the internal reef	Total number of fishes
0–20 m	34	22	56
20–40 m	21	22	43
40–60 m	21	23	44
60–80 m	7	16	23
80–100 m	3	3	6
Outside buffer area	2	2	4
Fishes in areas where reef has not been detected			4
Total:	**78**	**88**	**180**

Table 5: Extension of suitable habitat areas for humphead wrasse in six test areas in Indonesia.

Survey area	Length of coral reef slopes	Area of potential habitat
Bali Kangeam	1093 km	218 km^2
Banda Islands	450 km	90 km^2
Manado	514 km	103 km^2
Maratua	880 km	173 km^2
Nusa Tengara Komodo	748 km	150 km^2
Raja Ampat	528 km	104 km^2

One simple explanation for the difference is that in the present study we focused only in the areas considered suitable for humphead wrasse, particularly the adults, while Burke, Selig and Spalding (2002) were interested in the whole reef area. It is therefore to be expected that the total humphead wrasse habitat area, as defined in the present study, would be smaller than the total reef area. However, looking in more detail at the method used by Burke, Selig and Spalding (2002) we concluded that part of the difference is explained by the methods used. The analysis performed by Burke, Selig and Spalding (2002) was based on grid cells with a one km resolution and the estimated reef areas are rounded to two significant digits (or the nearest 100 km^2). Figure 22 demonstrates the difference between the two methods used based on a test area in the Banda Islands, Indonesia: a) the method used in the present study is much closer to the real location of the fringing reefs; b) the resolution of the one km grid cells used by Burke, Selig and Spalding (2002) do not allow a precise mapping of the reefs in narrow continental shelves like those in Indonesia. In the example shown in Figure 22 the total area defined by the one km cells is 71 km^2, while the habitat area defined by our work is 11.3 km^2 or only 16 percent of the areas defined by Burke, Selig and Spalding (2002) as reefs. We therefore conclude 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 adequate and more conservative than the previously available estimates of reef areas. The much smaller reef areas indicated in this study are also consistent with the considerably reduced coral reef areas indicated, on a global scale, by Andrefouet *et al*. (2004).

Table 6: Extension of humphead wrasse habitat area in Indonesia, Malaysia and Papua New Guinea calculated after the definition of reef edges and buffer areas on Landsat images.

Country	Habitat area
Indonesia	11 892 km^2
Malaysia	941 km^2
Papua New Guinea	5 254 km^2

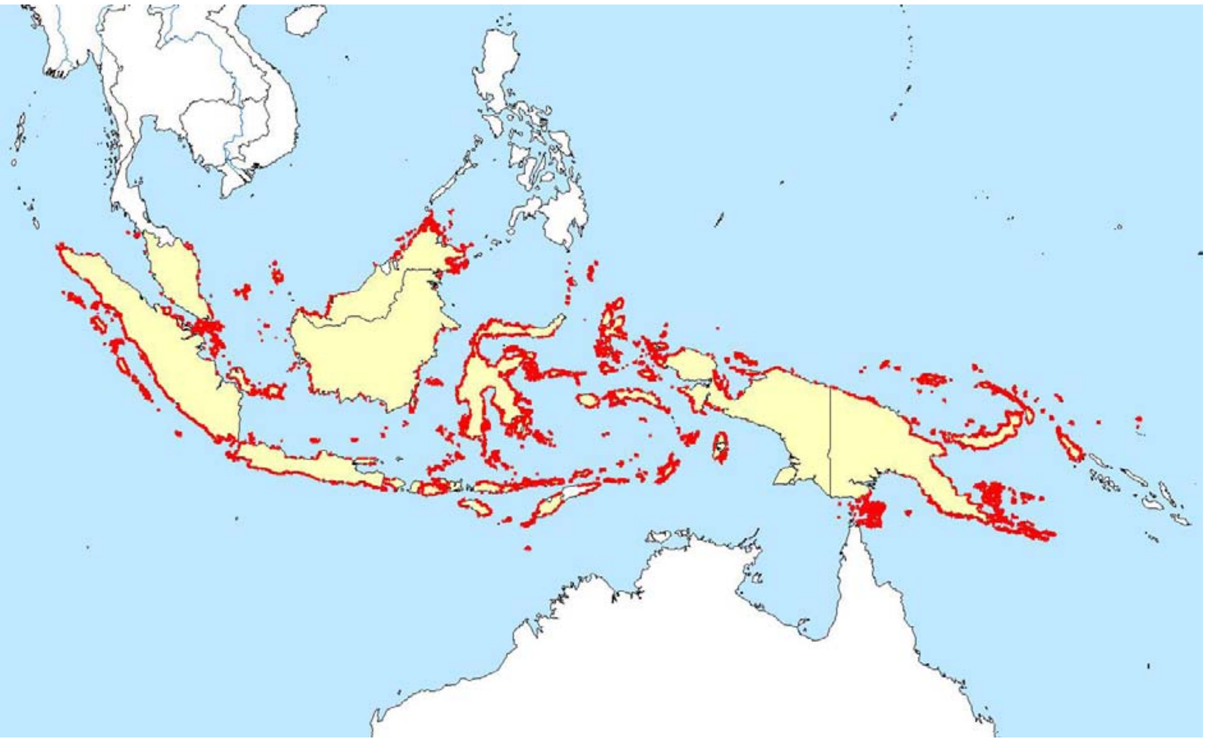

Figure 19: Humphead wrasse habitat area in Indonesia.

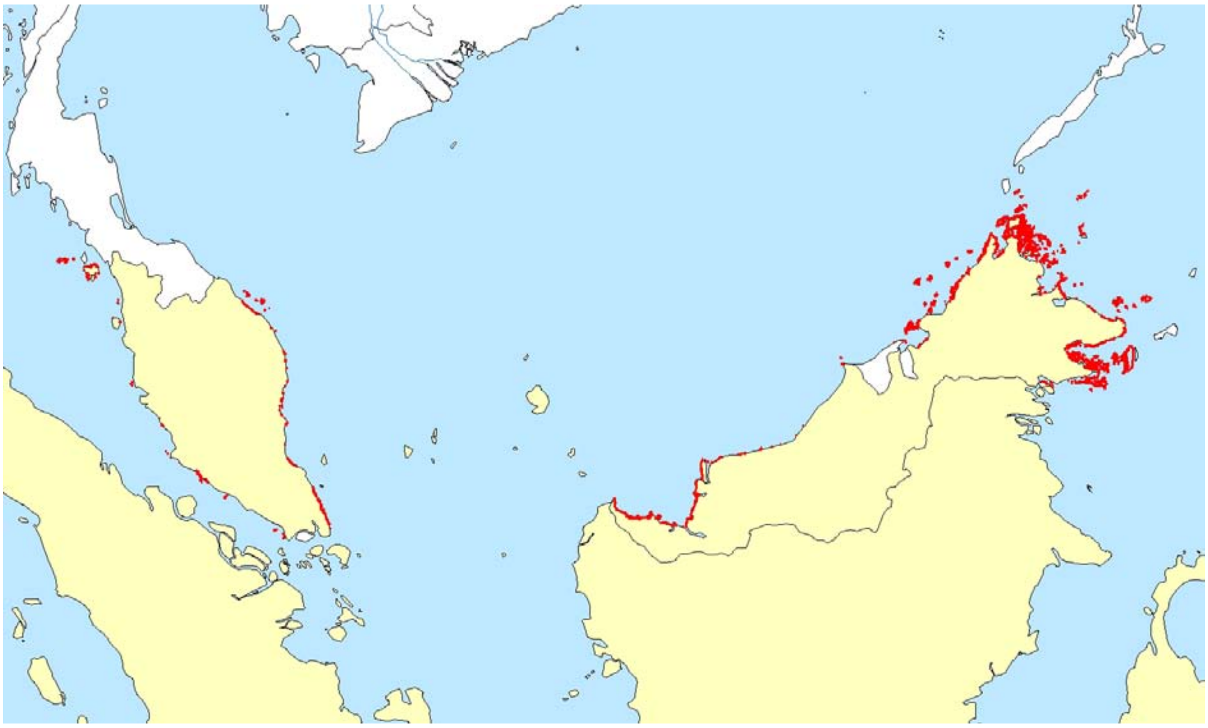

Figure 20: Humphead wrasse habitat area in Malaysia.

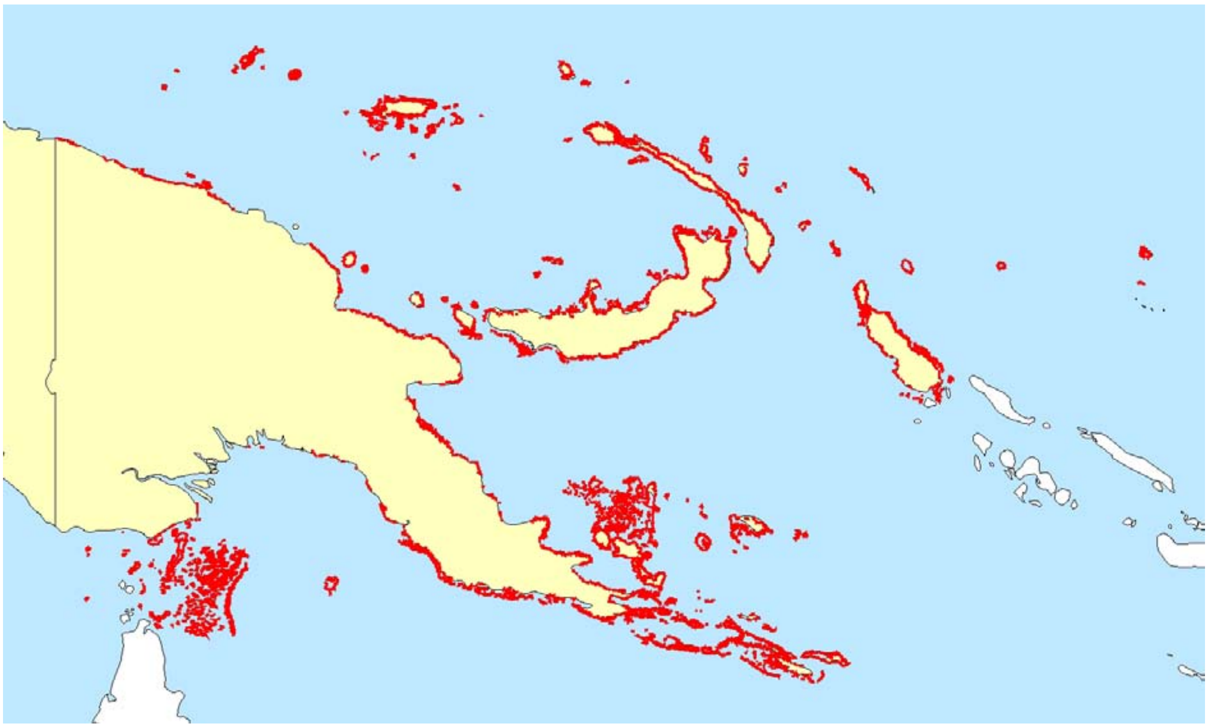

Figure 21: Humphead wrasse habitat area in Papua New Guinea.

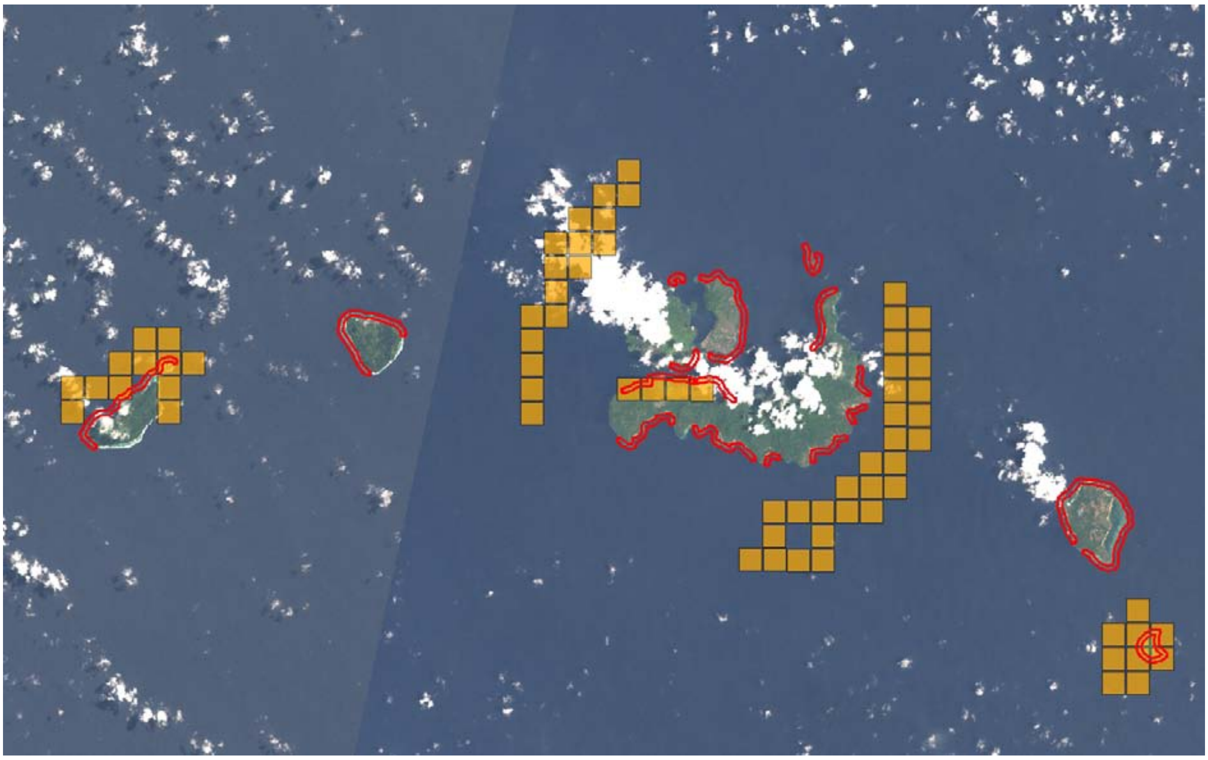

Figure 22: Humphead wrasse in reef habitat areas in the Banda Islands, Indonesia: comparison between current study (red outlines) and previous estimations (orange squares) by Burke, Selig and Spalding 2002

3.1 Some issues related to the application of the method

The case study recognised some main issues and challenges related to the above approach to mapping. In relation to the remote sensing analysis, they are concerned with aspects such as:

i. reef areas that are not well defined or are too small to be detected in a Landsat image;
ii. areas close to river mouths where the discharge of sediments affects the ability to visualize structures below the surface (although areas with high turbidity are naturally unsuitable for coral reefs);
iii. the difficulty in discriminating between live and dead coral;
iv. GIS worker's experience in RS image analysis (some experience is helpful).
v. habitat mapping, which can be complicated and time-consuming, especially for large and complex areas like Indonesia,

It is also likely that in reality humphead wrasse distribution would be affected by factors other than the position of the edge of the reef. These include the availability of food, wave strength and height, existence of algae, etc. Nonetheless, the study presents a simple, though effective, methodology that could couple the use of remote sensing images with the analytical capabilities of GIS.

3.2 Concluding remarks

The use of Landsat satellite images appears to be an objective way to detect coral reefs, and the habitat of reef-associated species, such as the humphead wrasse, over large sea areas. At present there is no automatic procedure to extract information about reef areas from Landsat images; a considerable level of manual work is required to perform the analysis. The habitat mapping can be a complex and time-consuming process, especially for large and complex areas like Indonesia, Malaysia and Papua New Guinea, where there are different coral structures and variable atmospheric conditions and sea status. The skill of the operator in having a clear understanding of photogrammetric coral reef detection in a 30 m resolution Landsat image is also a crucial aspect, and further tests and in-situ analysis may show some level of discrepancy with the results obtained. Nonetheless, overall, we are confident that the habitat areas estimated in this study are much more accurate than those previously used to estimate the population size of humphead wrasse (e.g. Sadovy *et al*., 2007).

Satellite images are an independent source of objective information that can be instrumental in identifying habitat areas in a relatively rapid and cost effective way. They also offer a continuous source of information in time and space that could be used to monitor the impact of human activities on these habitats. In this regard, further developments could be made to use satellite images to investigate the impact of common stressors on coral reefs habitats, such as:

- large human settlements in coastal areas;
- the intensity of land runoff and the siltation of coastal waters caused by both human and natural impacts;
- areas of heavy ship movements (e.g. the Malacca strait near Singapore) where the risk of oil spills is higher;
- impact of natural phenomena on the coral reefs (e.g. typhoons and tsunamis).