Title: MAPPING COASTAL AQUACULTURE AND FISHERIES STRUCTURES BY SATELLITE IMAGING RADAR. CASE STUDY OF THE LINGAYEN GULF, THE PHILIPPINES.

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Application Tool: Remote sensing.

Main Issues Addressed: Inventory and monitoring of aquaculture and the environment.

The general problem, or aim of the study, and the contribution of GIS, remote sensing and/or mapping to the solving the problem: Inventory and monitoring of coastal aquaculture and fisheries structures provide important baseline data for decision-making in planning and development, including regulatory laws, environmental protection and revenue collection. Mapping these structures can be performed with good accuracy and at regular intervals by satellite remote sensing, which allows observation of vast areas, often of difficult accessibility, at a fraction of the cost of traditional surveys. Satellite imaging radar (SAR) data are unique for this task not only for their inherent all-weather capabilities, very important as aquaculture activities mainly occur in tropical and subtropical areas, but essentially because the backscatter from the structure components allows for their identification and separation from other features. The area selected and object of the study has been Lingayen Gulf, sited in northwestern Luzon Island, the Philippines, where all these structures of interest occur. Field verification of the methodology resulted in the following accuracy: fishponds 95 percent, fish pens 100 percent. Mapping accuracy for fish cages was estimated at 90 percent and for fish traps at 70 percent. The study is based on interpretation of SAR satellite data and a detailed image analysis procedure is described. The report aims at the necessary technology transfer for an operational use of the approach indicated in other similar environments.

Main Environments: Brackishwater

Culture Systems: Cages.

Organism Divisions: Marine Fishes, Crustaceans

Genera and Species: Milkfish (*Chanos chanos*), Rabbit fishes (*Siganus* spp.)

Target Country: The study was conducted in the Lingayen Gulf, the Philippines but has applicability in other similar environments worldwide.

Target Audience: The present study is aimed at the general fisheries and aquaculture public, governmental administrators and planners and remote sensing and GIS specialists.

Duration of the Study and Year Begun: 6 months, the study began in 2003 and ended in 2004.

Personnel Involved:

Remote sensing specialist with a working knowledge of remote sensing applications in fisheries and aquaculture (FAO Remote Sensing Officer); assisted with the design of the study and analyses, and managed the project; full time.

Fisheries and aquaculture specialist with a working knowledge of GIS and remote sensing applications (FAO Fishery Resources Officer); assisted with the design of the study; part-time for the duration.

Digital image processing specialist (Consultant and Professor); modelling, image processing and analyses; full time.

Philippine Aquaculturist who wrote the description of the structures: fish pens, cages and traps and played a key role in ground verification; part-time for the duration.

Field verification personnel from BFAR (4); full time for short duration.

Advisers at large (4), who provided data and advice from time to time.

MAPPING COASTAL AQUACULTURE AND FISHERIES STRUCTURES BY SATELLITE IMAGING RADAR. CASE STUDY OF THE LINGAYEN GULF, THE PHILIPPINES

Introduction

The Sri Lanka experience on mapping inland aquacultural farms

In 1999, in the framework of the assistance provided to the FAO project TCP/SRL/6712 "Revitalization and Acceleration of Aquaculture Development" in its inventory and monitoring of shrimp farms in northwestern Sri Lanka, the FAO Services "Environment and Natural Resources" (SDRN) and "Inland Water Resources and Aquaculture" (FIRI) jointly conducted a pilot study with a view to develop and field test adequate methodologies for future use in similar environments elsewhere. The Sri Lanka Government required up to date information on the spatial distribution of shrimp farms in order to enforce development regulations and to ensure a productive environment for shrimp farming with the least impact on the other uses of land and water resources.

The FAO project TCP/SRL/6712 provided an unique opportunity to test under operative conditions an innovative methodology for inventory and monitoring of shrimp farms and the support of a field team for the ground verification of the results and, thus, of the methodology's accuracy. It was immediately evident to the authors (Travaglia, Kapetsky and Profeti, 1999) that satellite imaging radar was the only tool available for achieving good results. Synthetic Aperture Radar (SAR) data are unique for mapping shrimp farms, not only for their inherent all-weather capabilities, very important as shrimp farms occur in tropical and subtropical areas, often cloud covered, but mainly because the backscatter from the dykes surrounding the ponds allows for recognition and separation of shrimp ponds from all other water covered surfaces. This is not possible with satellite data operating in the visible and near/mid infrared portion of the electromagnetic spectrum, because of the frequent clouds coverage and of the difficulty of discriminating the artisanal shrimp farms, with their small area and irregular shape, from other water covered surfaces, such as flooded rice paddies and flooded areas.

ERS SAR satellite data, acquired over the area in 1996, 1998 and 1999, were processed for shrimp farms inventory and the resulting information was compared to substantiate changes and trends in the development of shrimp farms. Ground verification indicated an accuracy of 86 percent. Subsequent calibration of the interpretation keys resulting from the ground truthing increased the accuracy of the approach, thus the final methodology is more than 90 percent accurate.

Objective of the study

Having developed and field tested a methodology for inventory and monitoring of inland fisheries structures (Travaglia, Kapetsky, and Profeti 1999), which could be applied in similar environments worldwide, the authors decided to expand the study to cover other structures, such as fish pens, fish cages and fish traps.

Therefore, the objective of the present study has been to develop and field test a methodology, based on satellite imaging radar (SAR) to inventory and monitor coastal aquaculture and fisheries structures, including accuracy evaluation. The Lingayen Gulf, in northern Philippines (Figure 1), where all structures under study are present (McManus and Chua, 1990; Palma,1989; Palma, Legasto, and Paw,1989) was selected as test area and the assistance to this exercise by the Bureau of Fisheries and Aquatic Resources of the Philippines was secured.

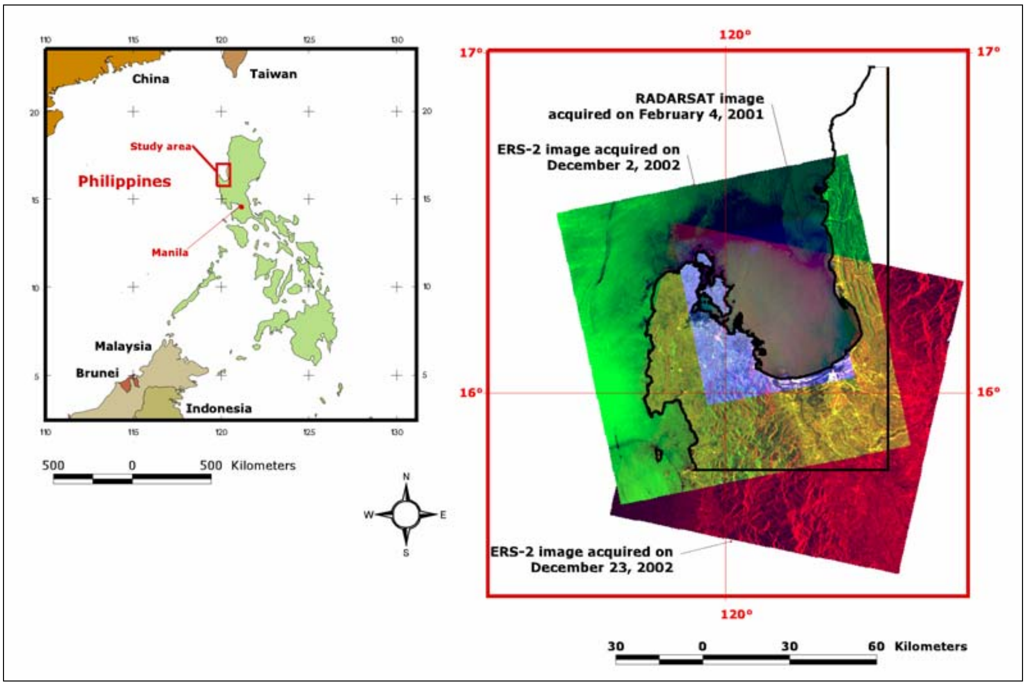

Figure 1: The study area and the zones covered by the satellite data.

Description of the structures: Fishponds, Fish pens, cages and traps.

Fishponds are small enclaves of calm water surrounded by dykes on all sides. A dyke is an earthen wall whose thickness ranges approximately from half a metre to several metres, and whose elevation from the water surface is at the most a metre.

Fish pens

Fish pens are fenced, netted structures fixed to the bottom substrate and allowing free water exchange. In the intertidal zone, they may be solid-walled. The bottom of the structure, however, is always formed by the natural bottom of the water body where it is built; usually coastal e.g. in bays, fjords, lagoons, but also inland e.g. in lakes, reservoirs. A pen generally encloses a relatively large volume of water.

Fish cages

Fish cages are rearing facilities closed at the bottom as well as on the sides by wooden, mesh or net screens. This allows natural water exchange through the lateral sides and in most cases below the cage. Most recently, imported and locally modified Norwegian cages are employed for the mass culture of milkfish in the gulf. Shapes and sizes of individual cages vary from quadrangular (10 x 10 x 8 m) partitioned into a cluster of compartments, or cylindrical (10–20 m x 10 m).

Fish traps

A fish trap is a device designed to encourage fish to enter a confined space and to prevent fish from leaving once they have entered. A fish trap may be of many sizes and configurations but usually it has an entrance, some form of non-return structure and a capture chamber. May be made of local materials or commercially bought wire mesh or netting. A fish trap may be set unbaited or baited depending on the target species.

Methods and Results

Data used

The study area is completely covered by two ERS-2 SAR images acquired on 2 December and 23 December 2002 respectively. The spatial resolution of ERS-2 SAR images is of 12.5 x 12.5 m. The two images were provided by the European Space Agency (ESA), in the context of their scientific research programme, in the Ellipsoid Geocoded Format (GEC). These images are system and ground range corrected, and were georeferenced and rectified into the Universal Transverse Mercator Projection (ellipsoid WGS84, zone 51 N). They have not been corrected for terrain distortion, as this was not necessary, the aquaculture and fisheries structures occurring in flat areas. The two images were specifically acquired by ESA for this study, by selecting two acquisitions made during descending and ascending orbits with the least possible time interval in-between. Orbit direction during the acquisition is extremely relevant because in descending orbits the scanning direction of the sensor is approximately opposite to that in ascending orbits. This in turn influences the characteristics of the SAR images, in which features are enhanced in a complementary way.

A RADARSAT-1 SAR image acquired on 4 February 2001 in the Georeferenced Fine Resolution (SGF) format was purchased from RADARSAT International. Its ground resolution is of 6.25 x 6.25 m. This image is also ground range and system corrected, and has been georeferenced and rectified into the geographic system, ellipsoid WGS72. It does not cover the entire study area, but includes the zones where the majority of the aquaculture and fisheries structures are located (Table 1).

Both images were reprojected into the reference projection of cartographic data (geographic system, ellipsoid Clarke 1866, datum Luzon).

In the study of coastal features and of some aquaculture and fisheries structures, the tide stage at the time of acquisition of the radar data may be of interest. For some considerations, images should be acquired at high tide, in order to delineate the land that is submerged only in exceptionally high tides. This would allow to reduce uncertainties in the visual interpretation stage, as coral reefs, sand bars and other coastal features are submerged.

The coastline charted in the topographic maps (McManus and Chua, 1990) is usually derived at the average high tide level and, therefore, could be directly compared with the one obtained from the images. On the other hand, radar data acquired at low tide would definitely enhance the possibility of mapping fish traps, the surface reflecting the radar beams being greater. Unfortunately, the only tide measuring station in the study area is in San Fernando, which is located almost outside Lingayen Gulf. Due to the conformation of the gulf, the tidal range is greatest along the coast inside it, and particularly in its southernmost part.

Table 1: Characteristics of the satellite data used.

Image type, pixel size	**Orbit, frame**	**Heading (deg. from North), path**	**Acquisition date (y/m/d)**	**Corner coordinates**		
					N	E
ERS-2 SAR GEC[1] 12.5 x 12.5 m	39830, 315	347.348 ascending	2002/12/02	UL	15.54	119.48
				UR	16.72	120.38
				LR	15.82	120.58
				LL	15.64	119.68
	40123, 3285	192.640 descending	2002/12/23	UL	16.52	119.84
				UR	16.33	120.74
				LR	15.43	120.54
				LL	15.61	119.64
RADARSAT-1 SAR SGF[2] 6.25 x 6.25 m	27423, path image[3]	347.318 ascending	2001/02/04	UL	16.45	119.84
				UR	16.54	120.30
				LR	16.04	120.40
				LL	15.95	119.94

[1] Ellipsoid Geocoded Image.
[2] SAR Georeferenced Fine resolution.
[3] Floating along-track between two frames.

Thus, the tide stage cannot be derived from the records obtained in San Fernando, and consequently it has not been taken into account in the selection of the images. Hence, the choice of the image acquisition period was based only on the season. All images were acquired in winter, during the dry season, when rice fields are not flooded. This allows to minimize the errors in the visual interpretation of the images.

Methods

Mapping aquaculture and fisheries structures by satellite imaging radar

Aquaculture structures are evident in SAR data because their components influence in a peculiar way the radar backscatter. An analysis of fishpond appearance on SAR data has already been conducted by the authors (Travaglia, Kapetsky and Profeti, 1990).

Fishponds are small enclaves of calm water surrounded by dykes on all sides. A dyke is an earthen wall whose thickness ranges approximately from half a metre to several metres, and whose elevation from the water surface is at the most a metre. While a calm water surface behaves like a specular reflector, sending only a small part of the signal back to the sensor, a dyke reflects back a large amount of the incoming energy, because its sides intersect the surrounding water at approximately a right angle, creating a “corner reflector” (Figure 2).

The return signal of elongated objects varies also as a function of the angle between the object and the cross-track direction (Figure 3). Surface features oriented in a parallel way with respect to the scanning direction are less evident than those oriented perpendicularly to the scanning direction. Hence, if a dyke is parallel to the cross-track direction, it may escape detection.

The ERS-2 satellite follows a quasi-polar orbit, and as described previously its scanning direction (or *cross-track* direction) is right of the sub-satellite track. Thus, in descending orbits (from the North Pole downwards) the scanning direction is approximately opposite to that in ascending orbits. Consequently, surface features are highlighted in a different, complementary way on a pair of images acquired respectively in ascending and descending orbits.

The angle between the scanning direction of the two ERS SAR images used in this study is of 152.708 degrees. A comparative analysis of both images allows to identify properly all features, if they are acquired at a short time interval in order to minimize changes over the imaged surfaces between the two acquisitions (Figure 4).

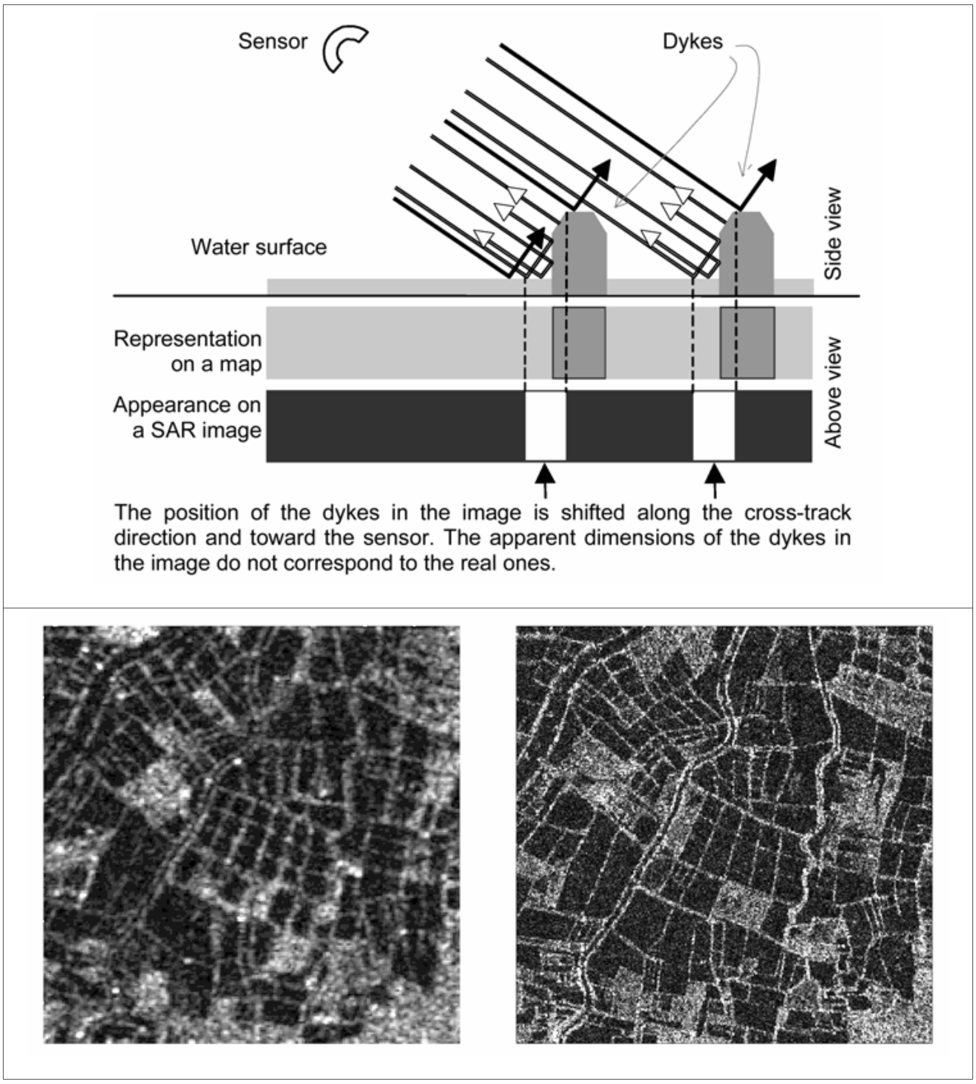

Figure 2: Above, interaction of radar beams with dykes and water surfaces on a group of fishponds. Below, appearance of fishponds in the ERS-2 SAR image of 2 December 2002 (left) and in the RADARSAT-1 SAR image of 4 February 2001 (right).

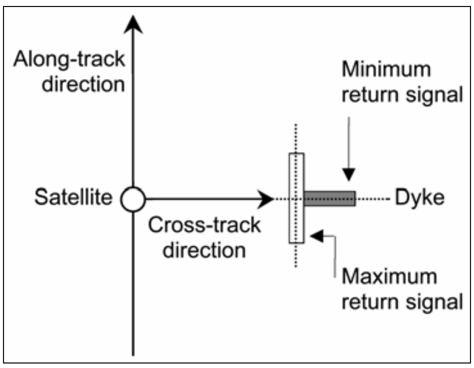

Figure 3: Return signal as a function of the angle between the dyke and the cross-track direction

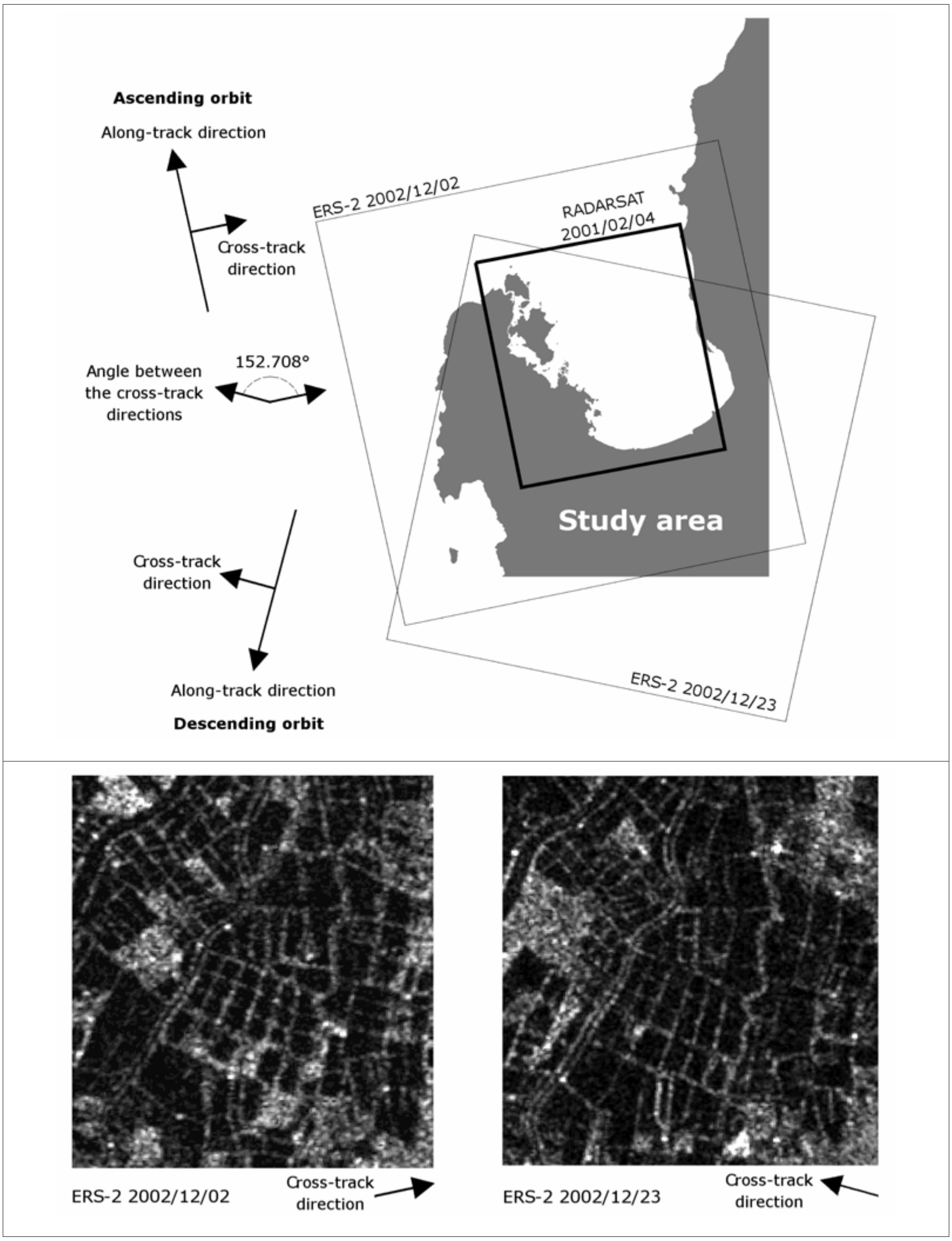

Figure 4: Above, the angle between the scanning directions in the SAR data used in the study. Below, differences in the fishpond pattern due to the diverse scanning directions in the ERS SAR images acquired on ascending and descending orbits.

The other aquaculture and fisheries structures influence the radar signal in a similar way. The vertical sides of fish cages, pens and traps, emerging from the water surface, create the corner reflector effect that allows to identify them.

For example, Figure 5 shows the interaction of SAR pulses with a fish cage. The sides of the cage oriented perpendicularly to the scanning direction are brighter in the SAR image. In the smaller cages, the extension of the water surface inside is very small with respect to the sensor resolution and may not be represented in the image. As a result, the cage will appear as a bright group of pixels on the dark sea surface. The same happens to the smaller fish pens.

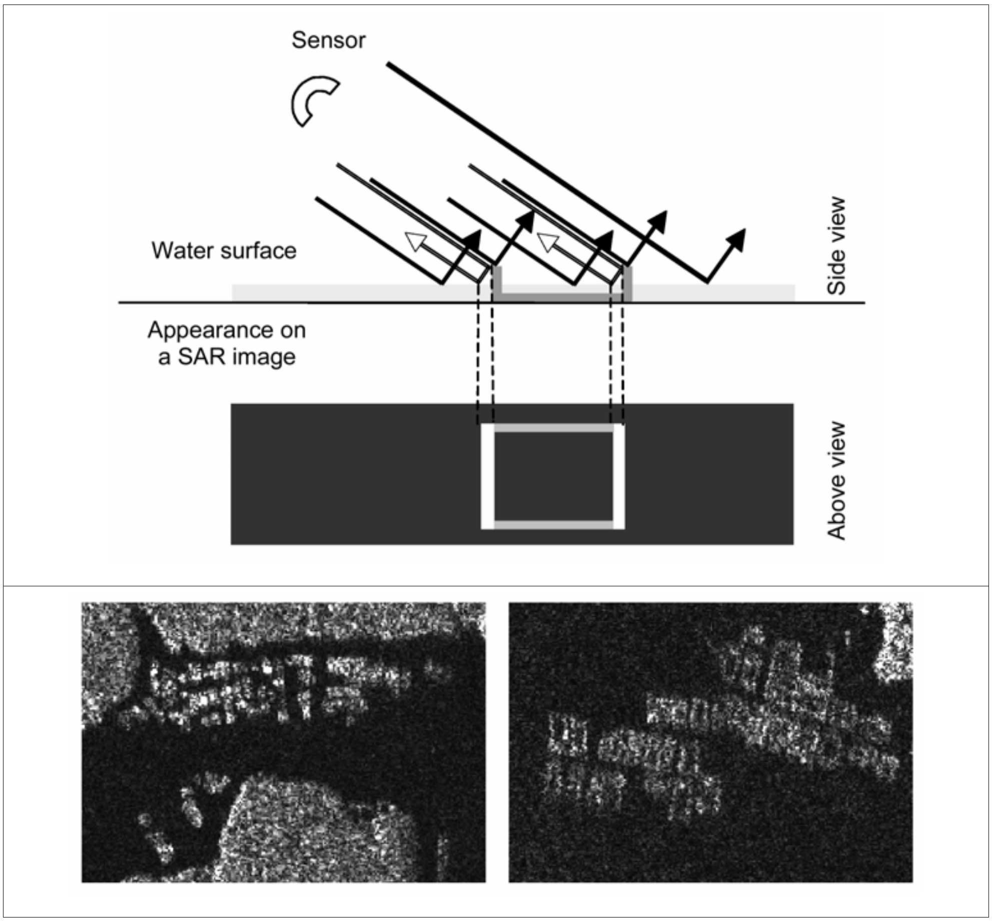

Figure 5: Above, interactions of a radar beam with a fish cage. Below, appearance of small cages (left) and large cages (right) in a RADARSAT-1 image.

Finally, the appearance of the structures in the SAR imagery is also greatly influenced by the spatial resolution of the sensor. Fisheries structures are generally made out of thin components and cover limited extensions; thus, the highest the spatial resolution the higher the possibility of detecting them. In particular, the smaller fish pens may not be evident in ERS SAR images, and fish traps are generally too thin to be detected; they appear only in the higher-resolution RADARSAT image.

Results

The results obtained by the visual interpretation of the SAR images and the comparison with the data obtained from the topographic maps of 1977 are reported in this paragraph. Results refer to the area under study, that is the area covered by the satellite frames, and to the period of acquisition of the satellite data.

Fishponds

Fishponds occupy the largest surface of all the structures occurring in the area. It is interesting to compare the surface occupied by fishponds in the year 2002 (excluding the class fishponds/uncertain) with their area coverage mapped in the 1977 cartography. The cartography showed three types of fishponds: active, empty, and active containing nipa . Fishponds are routinely emptied for maintenance purposes, and nipa trees are cultivated inside active fishponds; thus, in order to perform a correct comparison, the cumulative surface covered by these three classes in the cartography of 1977 has been calculated. The results are shown in Table 2: the cumulative area occupied by fishponds has increased. It must be noted that this does not correspond to a simple expansion of the fishponds existing in 1977. Some of the ponds mapped in 1977 were converted to other uses (e.g. commercial lots). Fishponds appear in SAR images as shown in Figure 2.

Table 2: Length of the fish traps detected in the study area

Class Description	N. of elements	Cumulative length (km)	Average length (km)	Min length (km)	Max length (km)	Std deviation
Traps in the open sea	378	50.104	0.133	0.018	0.642	0.093
Traps inside rivers	84	7.886	0.094	0.024	0.036	0.061

Fish pens

Fish pens were detected only on RADARSAT-1 data, as explained in the preceeding paragraph. The pens are located in the estuaries of the major rivers. In many cases, they are adjacent to fishponds. The 1977 cartography does not include fish pens, thus a comparison with the actual position and location is not possible. Figure 6 shows the typical appearance of fish pens on SAR images.

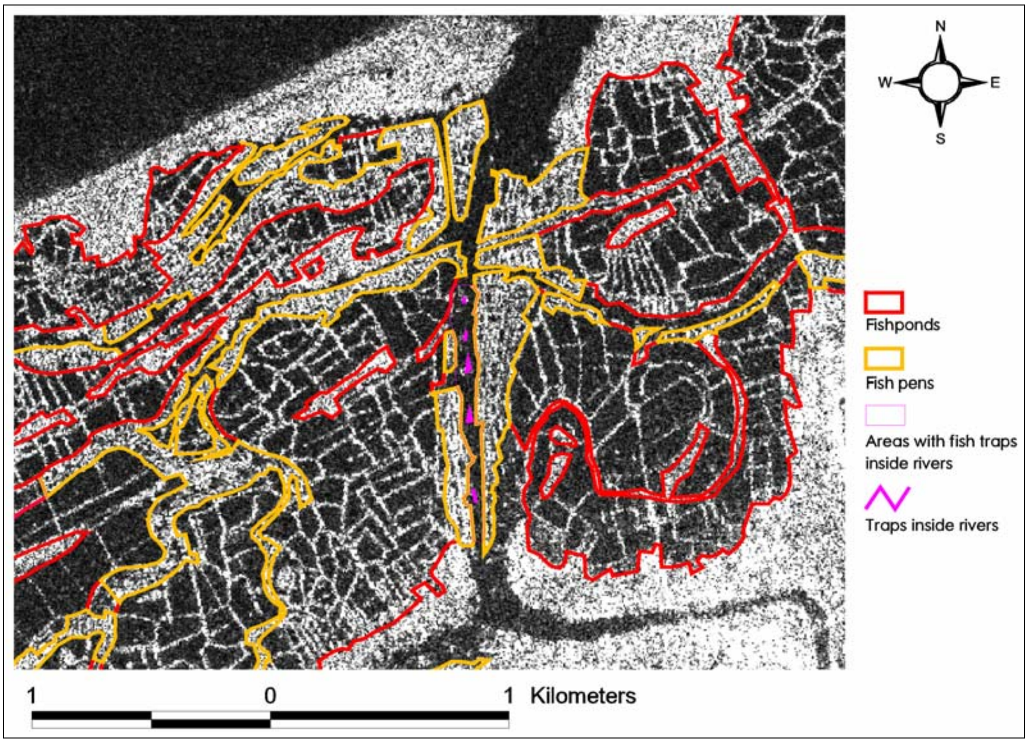

Figure 6: Interpreted RADARSAT-1 SAR image.

Fish cages

Fish cages were detected both on the RADARSAT-1 image of 4 February 2001 and in the two ERS-2 images of 2002. They are more evident in the first ERS-2 image (2 December 2002), as in the second one (23 December 2002) the roughness of the sea surface and the low tide decreased the contrast between cages and the surrounding surfaces.

Fish cages may be of several shapes (square, rectangular, circular) and of various materials. Those made up mainly of metal have a brighter appearance on SAR images. In fact, in addition to the factors already described, the intensity of the SAR backscattered signal is proportional to the dielectric constant of the scattering surface; metals have high dielectric constants and generate a stronger return signal. Figure 7 shows the appearance on RADARSAT-1 SAR and ERS-2 data of small metallic and non-metallic fish cages. Figure 8 shows the appearance of large cages on RADARSAT-1 SAR data. Data on fish cages in 1977 are not available, thus a comparison with the actual area coverage and location is not possible.

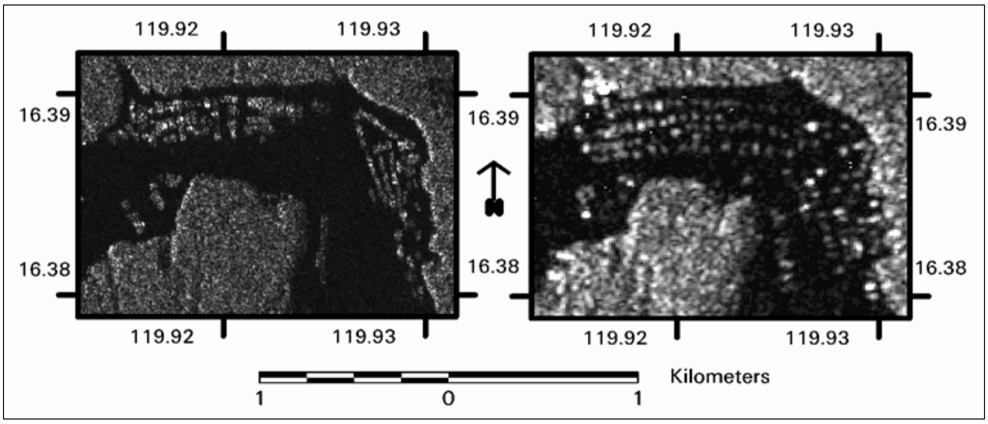

Figure 7: Appearance on RADARSAT-1 (left) and ERS-2 (right) images of small metallic and non-metallic fish cages. Metallic cages appear as brighter spots.

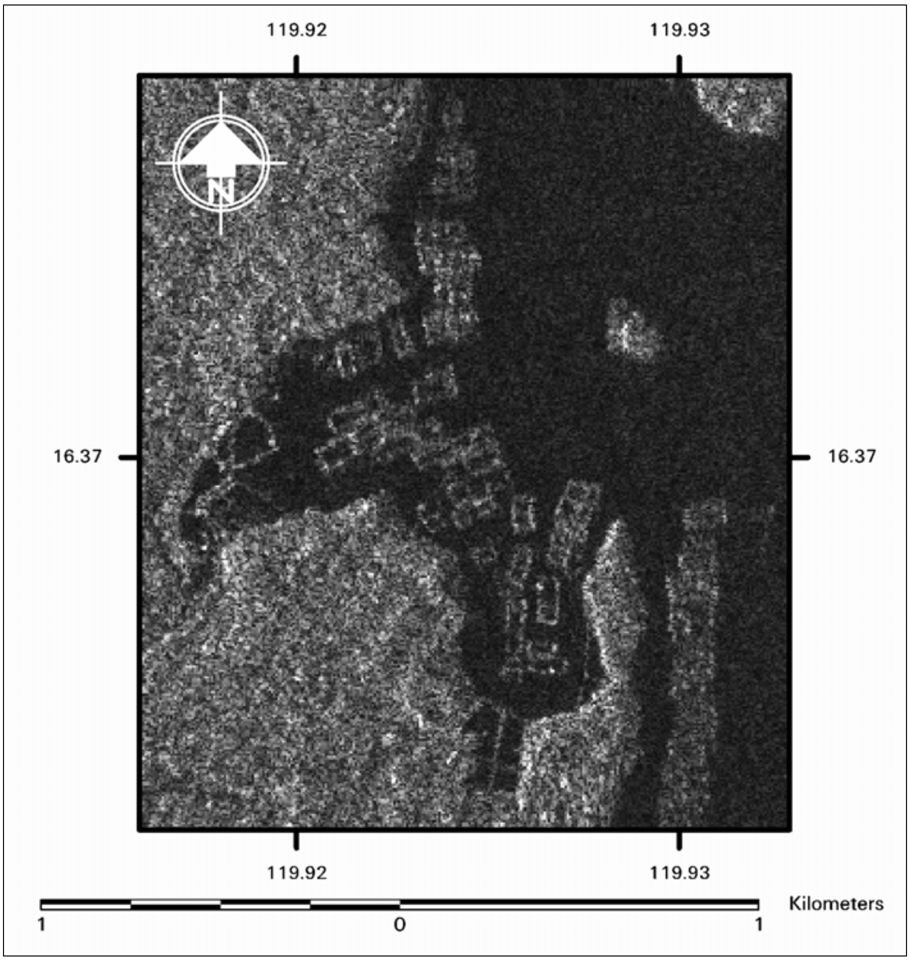

Figure 8: Appearance of large fish cages on RADARSAT-1 SAR data.

Fish traps

Fish traps were separated into two categories: offshore traps and traps inside major rivers. The areas occupied by fish traps were contoured only approximately to estimate their extension. Traps were detected only on RADARSAT-1 data of 2001. In many cases only the central structure of the traps is visible in the images; on the other hand, because of their dimensions the uncertainty on the identification of traps is higher than that of the other structures. Figure 9 and Figure 10 show respectively the typical appearance of offshore traps and traps inside major rivers on RADARSAT-1 SAR images. Traps were not mapped in the cartography of 1977, thus a comparison with the past situation is not possible.

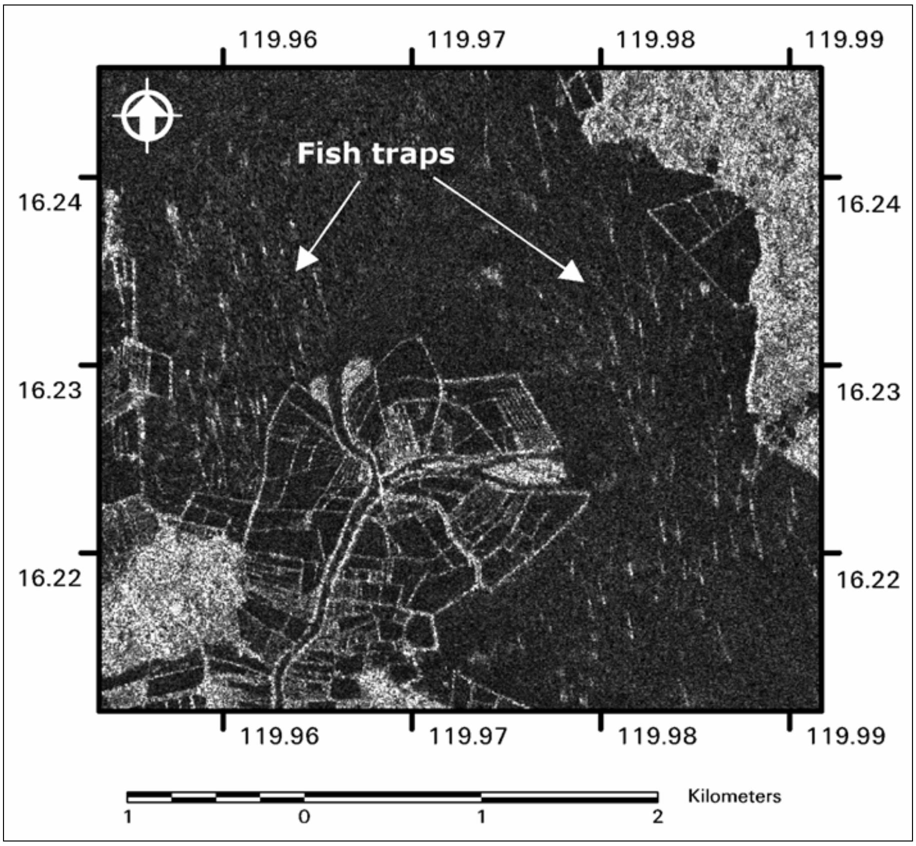

Figure 9: Appearance of offshore fish traps on the RADARSAT-1 SAR image.

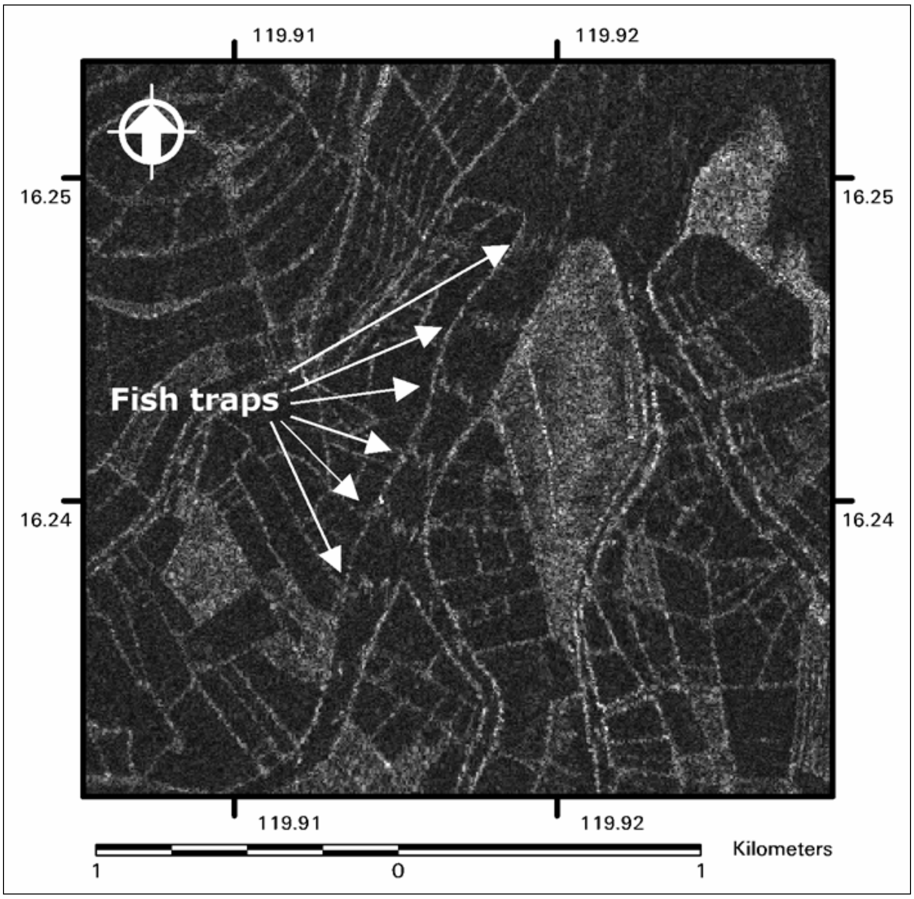

Figure 10: Appearance of fish traps inside rivers on the RADARSAT-1 SAR image.

Field verification exercise

A team of the Bureau of Fisheries and Aquatic Resources of the Philippines (BFAR) went in December 2003 to Lingayen Gulf to check the accuracy of the interpretation of SAR images. Before discussing the field validation results, the following aspects of the work should be considered:

1. Fish traps were recognized only on RADARSAT data which were acquired on February 2001, that is about two years before the field check. Some of them could have been removed or moved somewhere else in this timeframe;

2. Fish cages were easily mapped with both RADARSAT-1 and ERS-2 data. As the cages are floating, they can be moved to other places if there is a need. Actually, a group of cages located between Luzon Island, Santiago Island and Cabarruyan Island presents two distinct locations in RADARSAT-1 (February 2001) and in ERS-2 (December 2002), most probably as a consequence of a typhoon which affected the area. Thus the field checking of fish cages was limited to ascertaining the presence of fish cages in the vicinity of the place indicated in our SAR-derived maps, as in a one year interval the cages could have been moved somewhat. However, in the majority of the cases, the fish cages were still at the places mapped from radar data.

3. Fish pens and fishponds, being semi-permanent structures, were not influenced by the one year time interval and thus they were field checked at the exact coordinates reported in the radar-derived maps. In limited cases fishponds were converted to other uses in the most recent months, but interviews with local people confirmed their original nature.

The field work was thus aimed at mainly verifying the interpretation of fishponds and fish pens. The survey was conducted on 32 verification points, selected by means of a two-stage cluster sampling scheme. Two verification points were also located on the “fishponds, uncertain” class, as the results could have assisted in fine-tuning the interpretation keys. The ground verification included also six observation points located offshore and inside rivers, in order to confirm the presence of fish cages and traps in/or the proximity of the points in which they are located in the SAR images.

The analysis of the ground truth at the verification points shows that both the two points located on the class “fishponds, uncertain” are in fact other types of water-covered surfaces. This confirms the correctness of the main interpretation key, according to which the water-covered surfaces were assigned to the class fishponds only if the surrounding dykes were visible. Water-covered surfaces regular in shape but not surrounded by visible dykes were assigned to the class “fishponds, uncertain”; the results of the ground survey demonstrate that the class “fishponds, uncertain” should be removed from the final map. Of the other 30 verification points, 23 are located on areas interpreted as fishponds, four on fish pens and three on salt pans. The actual land use was different at one point only; it had been assigned to fishponds by the visual interpretation, but the corresponding area is a marshland bordering salt pans.

The user’s accuracy of the verified classes, e.g. the ratio between the total number of points truly belonging to a class and the total number of points assigned to the same class by the visual interpretation procedure, is thus 100 percent for salt pans and fish pens, and 95.7 percent for fishponds. These figures give the probability that a point on the interpretation map truly corresponds to the class to which it has been assigned. However, the actual accuracy of the “salt pans” class might be lower, due to the fact that they may appear very similar to fishponds when they are completely flooded.

The accuracy cannot be calculated for fish cages and traps, as they may have been moved or removed in the time interval between the image acquisition and the field verification, as a consequence of severe weather conditions. In fact, differences in their positions are visible on the 2001 and 2002 images, as explained above. Thus, mapping accuracy for fish cages was estimated at 90 percent and for fish traps at 70 percent. The results of the ground survey show that offshore fish traps are still approximately located in the same areas in which they were when the images were acquired, while the traps detected inside rivers were not observed in the two surveyed points. The fish cages at the southern border of Santiago Island, clearly visible in all SAR images, are still located there, while the fish cages identified offshore Barangay Dori (Bolinao) are now replaced by fish pens built seaward from the rocky coastline.

Discussion

RADARSAT fine beam

RADARSAT fine beam data, thanks to their ground resolution of 6.25 m, provide excellent images of all aquaculture and fisheries structures considered in this study and, therefore, allow for their inventory and monitoring with great accuracy. Actually, fish pens were detected and easily mapped only with RADARSAT data. Similarly, fish traps were visible only on the RADARSAT image, but their mapping was not immediate due to the inherent characteristics of the traps themselves.

Having considered these evident advantages, some other aspects of RADARSAT data should be evaluated: a RADARSAT fine beam frame covers only 50 x 50 km at a cost of US$ 3000 if the image has been already acquired and is available (archive data). Satellite programming cost is US$ 100 but goes up to US$ 500 if an acquisition date is booked in advance.

ERS SAR

ERS SAR data in their GEC format have a ground resolution of 12.5 m and cover a 100 x 100 km area. Fishponds and fish cages were easily mapped through ERS SAR data during this study with accuracy comparable to that of RADARSAT. An ERS SAR frame costs US$ 1400 for both archived and programmed data.

In the present study we had the possibility of having ERS SAR data both in ascending and descending orbit. As discussed, this is a distinct advantage as it greatly increases detection and, thus, accuracy in fishponds mapping. For mapping fishponds and fish cages we recommend using ERS SAR with data from ascending and descending orbits acquired with a limited time interval between dates of recording.

Final considerations

Mapping and monitoring coastal aquaculture and fisheries structures is extremely important for governments as this generates baseline information for decision-making for a proper development of aquaculture and fisheries, including regulatory laws, environmental protection and revenue collection.

This can be achieved with good accuracy and at regular intervals by satellite remote sensing, which allows observation of vast areas, often of difficult accessibility, at a fraction of the cost of traditional surveys. In several cases the information obtained through satellite remote sensing is unique, as it cannot be generated by any other means.

The mapping accuracy obtained with SAR data is very high: 100 percent for fish pens and 95 percent for fishponds. It has been difficult to field check the mapping accuracy for fish cages, as they are floating and thus movable if need arises. However, their clear appearance on the SAR data, including information on their metallic/non metallic structure and the fact that they cannot be mistaken for any other object, permit a 90 percent estimated mapping accuracy.

Fish traps are detectable only on RADARSAT fine beam data, both offshore and inside river estuaries. Often their length can be measured. Being thin elongated structures almost completely under the water, their backscatter on SAR data should be maximum at low tide. Unfortunately, as indicated in section 4.1, tide information for the Lingayen Gulf was not available for the selection of the relevant data. Thus for fish traps it can be said that detectability on RADARSAT fine beam data is high and mapping accuracy can be estimated at 70 percent.

An extremely important aspect of aquaculture and fisheries structures mapping by satellite imaging radar (SAR) is that the resulting maps are geocoded and available in a Geographic Information System (GIS) as information layers. By adding other GIS layers such as land cover, urban development, tourist sites, areas subjected to conservation measures, potential/existing pollutants, water quality and other information layers of interest, the resulting database becomes a powerful tool for a proper management and development of the local resources, including environmental protection.

Another important aspect which should be considered is that the database facilitates identifying land cover changes which occurred during the development of the structures, mainly fishponds, and/or selection of the best places for their expansion, taking into account other potential and often conflicting uses of the area.

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