2. Methodology

2.1 DATA AND SOFTWARE USED

The study area is completely covered by two ERS-2 SAR images acquired on 2 December and 23 December 2002 respectively (Figure 2 and Table 3). 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 occuring 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, as described in section 2.3.

TABLE 3
Characteristics of the satellite data used

Image type, pixel size	Orbit, frame	Heading, path *(degrees from North)*	Acquisition date *(year/month/day)*	Corner coordinates		
					N	E
ERS-2 SAR GEC[1] 12.5 x 12.5 m	39830, 315	347.348 ascending	2002/12/02	UL	16.54	119.48
				UR	16.73	120.39
				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	15.42	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.
UL= Upper Left, UR=Upper Right, LR= Lower Right, LL=Lower Left.

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 (Figure 2 and Table 3).

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 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.

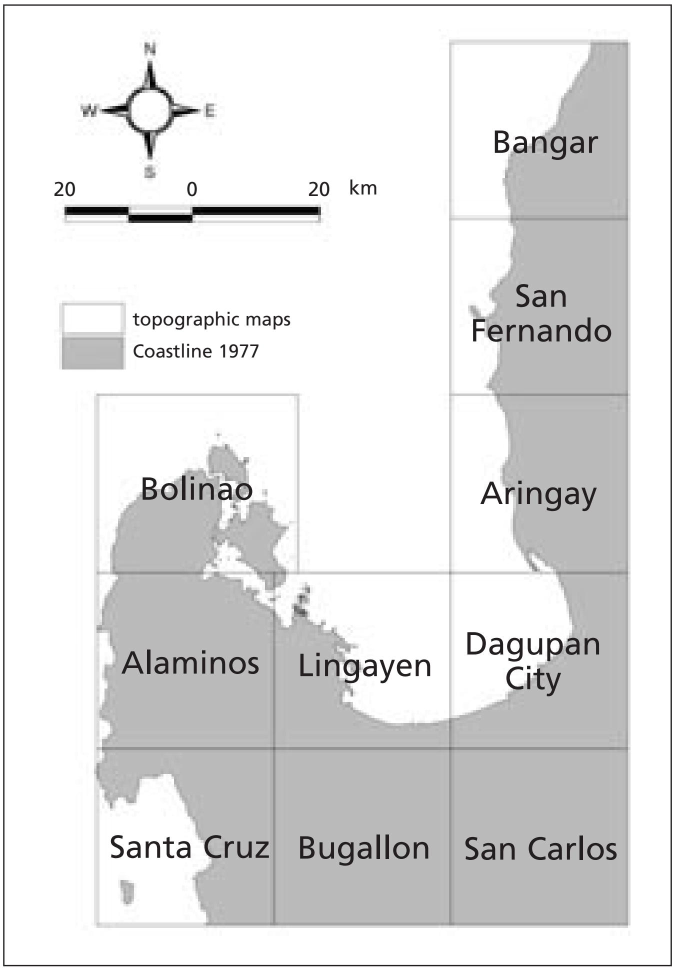
Unfortunately, the only tide measuring station in the study area is in San Fernando, which is located almost outside Lingayen Gulf. Due to the conformation of the gulf, the tidal range is greatest along the coast inside it, and particularly in its southernmost part. Thus, the tide stage cannot be derived 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.

The most detailed reference cartography available for the study area is a series of topographic maps at 1:50 000 scale, published in 1977. Data are mapped into the geographic system, ellipsoid Clarke 1866, datum Luzon. The study area is covered by ten topographic maps (Figure 6).

The maps were scanned and then the features of interest were digitized using the GIS software Arc View 3.2, as described in section 2.2.

FIGURE 6
Topographic maps, 1:50 000 scale, covering the study area



All the satellite images acquired for the present study were pre-processed and reprojected into the cartographic reference projection using the software Erdas IMAGINE 8.5. Satellite imagery and vector data were analysed jointly in the visual interpretation stage using the GIS software Arc View 3.2.

2.2 PREPARATION OF THE VECTOR DATABASE

The objective of the visual interpretation is to identify and map aquaculture and fisheries structures in the SAR images of the study area. These must be then compared with the cartographic data. The best strategy to perform this task is to create or transform all data in vector format, and analyse them using a GIS software.

For this reason, the first part of the preparatory work consisted in obtaining a vector database from the topographic maps of 1977, containing all the data relevant for this study. The maps were scanned at 300 dpi and the raster data thus obtained were geocoded by applying the rubber sheeting resampling procedure. This procedure puts each reference point at the given coordinates, and uses a linear interpolation to reproject the other elements of the grid. In this case, the reference points were the corners and all the grid intersections of each map. The vector information was then created by on-screen digitizing of the displayed raster maps. The scale of the topographic maps is 1:50 000, so to minimize errors the display scale for digitalization was 1:25 000 or larger.

Among the data reported on the topographic maps, only those relevant in the analysis of aquaculture and fisheries structures were digitized. Two layers were created in ArcView shapefile format, containing respectively polygons and polylines; in each case, the corresponding land cover and land use is specified by an attribute code.

The polygon layer contains the following classes:

Fishponds, empty fishponds, fishponds with nipa, and nipa

All these land use classes are directly relevant for the present study; the corresponding areas were digitized. In particular, adjacent groups of fishponds of the same category were digitized into the same polygon if they appear to be separated only by dykes, and as separate polygons otherwise.

A different code was assigned to the polygons of the four categories, as the related information might be useful in the subsequent analysis. As fishponds are periodically emptied for maintenance purposes, their being empty at the moment of the aerial survey upon which the maps are based does not necessarily imply that they were abandoned.

Regarding fishponds containing nipa palms (*Nypa fruticans,* Wurmb), this plant is extensively used as roofing material. Thus, it is sometimes grown inside fish ponds to increase their total revenue. Nipa palms emerging from water interact with the radar signal increasing the backscatter intensity over the pond surface; thus, data on their presence may be useful in the visual stage. For the same reason, nipa palms growing outside fishponds were mapped as well.

Mangroves

This land cover class is scarcely present in the study area.

Large rivers and lakes

Wide rivers can be easily identified in the SAR images. The knowledge of their boundary assists the interpreter in analysing the presence of fisheries structures inside the river itself, if its position and shape has not changed in time. In the study area, three of the largest rivers (Agno, Panto and Cayanga) actually show major modifications in the SAR data with respect to their position and extension reported in the topographic maps of 1977. The knowledge of the location and extension of natural lakes is also useful to avoid misinterpretation errors.

Actually, lakes are easily separated from fishponds as the latter are much more regular in shape and bounded by easily discerned dykes; however when the water-covered surface has a small extension, the dykes and the shape are less evident and errors may arise.

Salt pans
They cannot be separated from fishponds when they are flooded, thus knowing their location is useful to avoid interpretation errors.

Coral reefs, sand banks
Fishponds and other aquaculture structures may be built on open, shallow waters. Coral reefs have sometimes been destroyed to accommodate them, hence these areas were digitized to analyse whether this has occurred in the study area. On the contrary, sand banks are generally avoided as fishponds location because they correspond to areas where highly dynamic processes of sedimentation/erosion occur.

Mainland, islands
The coastline has been digitized as well; islands are included only if located in the open sea. The coastline on the maps corresponds to the mean lower low water. This layer has been compared with the coastline obtained from the 2001-2002 images, to enhance modifications that impacted on the location of aquaculture and fisheries structures. Digitizing of the coastline using the SAR images is described in section 2.5.

The polyline layer obtained from the topographic maps contains the following classes:

Roads and railroads
Includes the railroad and all types of roads; does not include tracks and trails. All roads have the same code. Roads and railways are relevant in the study of fishponds as they act as constraints for their expansion, facilitating at the same time fish transport to markets.

Rivers
Includes rivers whose width is too narrow to be represented in scale. The river network is an important element in the visual interpretation stage: fishponds must be connected to flowing water, and thus the ponds are always located in proximity of the main river network.

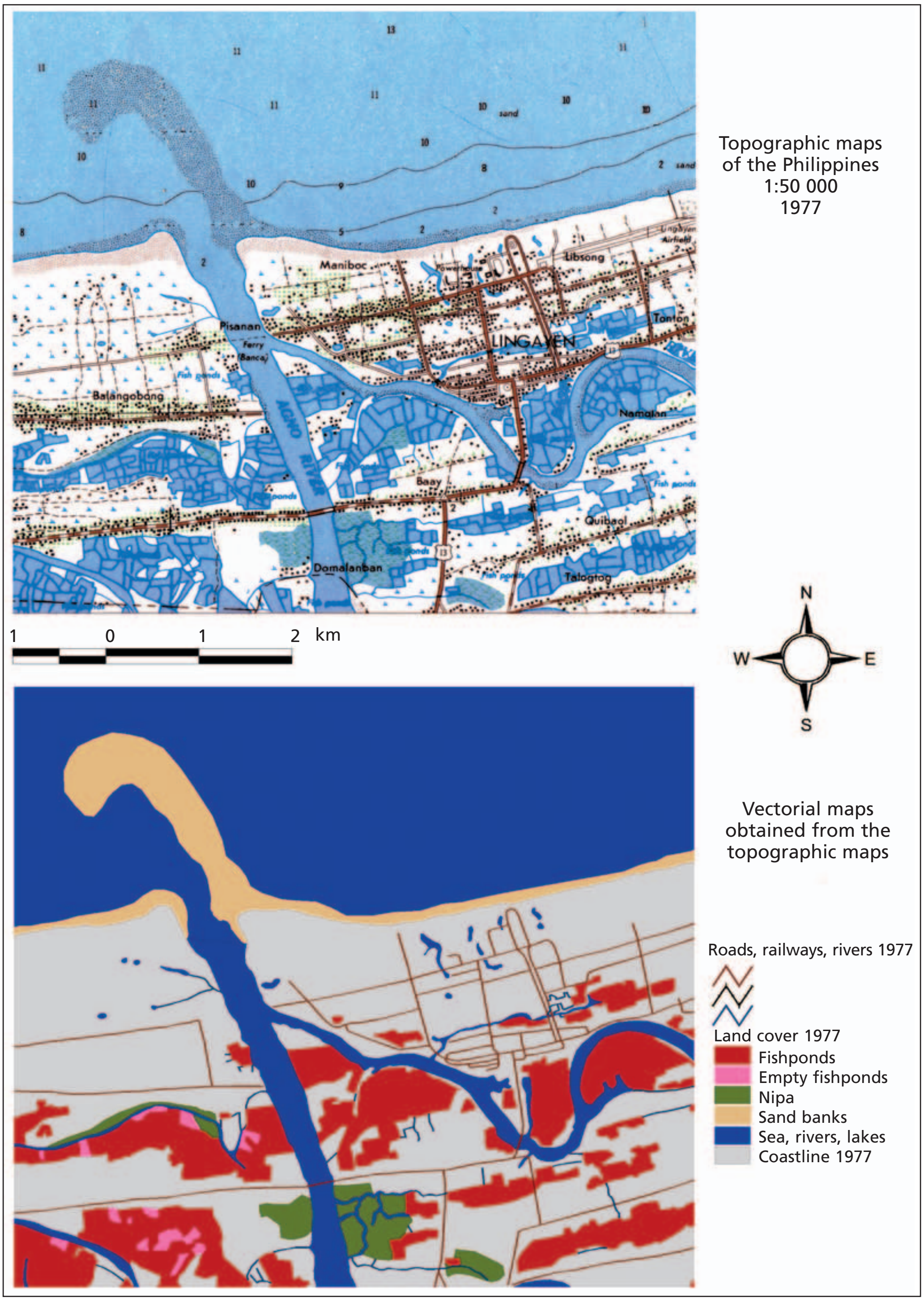
Figure 7 shows an example of the vector data obtained from the topographic maps.

2.3 MAPPING AQUACULTURE AND FISHERIES STRUCTURES BY SATELLITE IMAGING RADAR

Radar is the acronym of Radio Detection and Ranging. An imaging radar is an active device that transmits microwave pulses toward the Earth surface and measures the magnitude of the signal scattered back towards it. The return signals from different portions of the ground surface are combined to form an image. A Synthetic Aperture Radar (SAR) is a special type of imaging radar. It is a complex system that measures both the amplitude and phase of the return signals. Their analysis exploits the Doppler effect created by the motion of the spacecraft with respect to the imaged surface to achieve high ground resolution.

As the source of the electromagnetic radiation used to sense the Earth surface is the system itself, it can be operated during day and night. The atmospheric transmittance in the microwave interval used by remote sensing SAR systems is higher than 90 percent, even in the presence of ice and rain droplets (except under heavy tropical thunderstorms); thus, SAR can acquire data in all weather conditions.

FIGURE 7
A portion of Dagupan City topographic map (sheet 7074 II) and the derived vector data



A drawback of SAR imaging is the presence of noise (speckle) in the images. The noise is created by constructive and destructive interference between the backscattered energy from different portions of the ground surface included in the same cell (pixel) of the SAR image. The value of the pixel is thus increased or decreased; the SAR image appears to be covered by randomly scattered bright and dark spots.

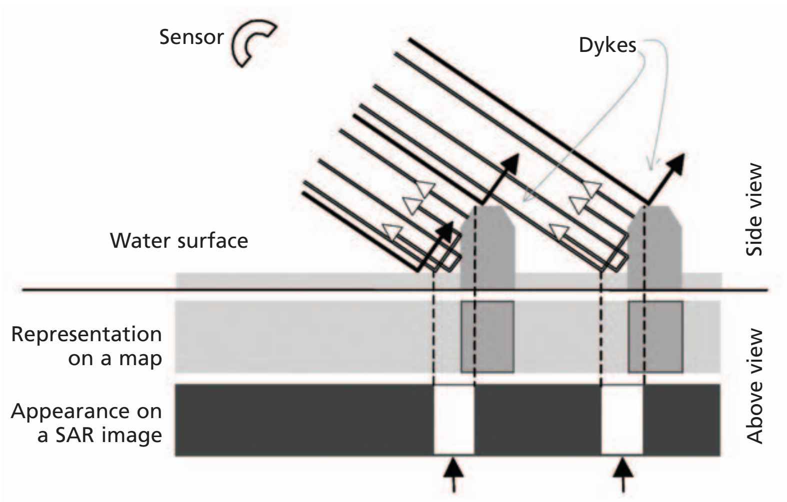
In all satellite imaging SAR systems, the pulses are emitted sideways, downwards to the Earth's surface and perpendicularly to the flight direction. The ERS SAR acquires strips of imagery approximately 100 km wide, 250 km to the right of the sub-satellite track; the incidence angle of the emitted pulses in the middle of the imaged stripe is 23°, and the ground resolution is of 12.5 x 12.5 m.

The SAR on board RADARSAT operates in several acquisition modes, obtaining images with varying resolution and size. To detect aquaculture and fisheries structures the highest possible resolution is necessary; this corresponds to the Fine Resolution acquisition mode. The ground resolution is 6.25 m; the acquired image is 50 km wide, it is located 385 km to the right of the sub-satellite track, and its mid-image incidence angle is of 44.259°.

Aquaculture structures are evident in SAR data because their components influence in a peculiar way the radar backscatter.

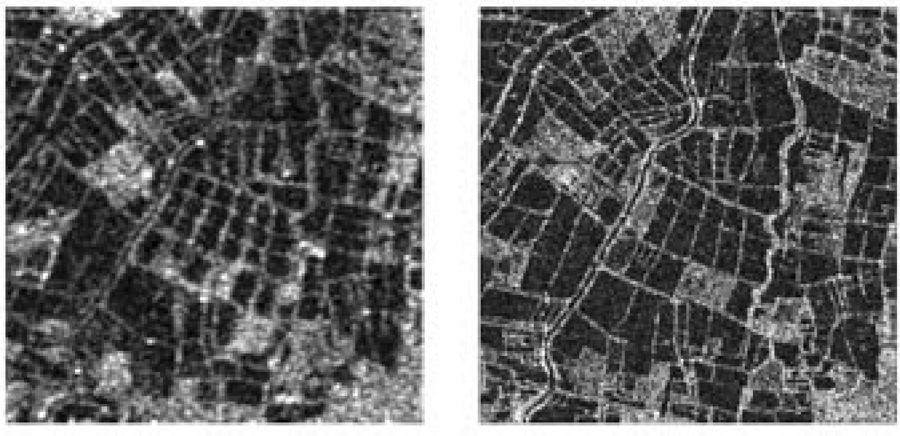
An analysis of fishpond appearance on SAR data has already been conducted by Travaglia, Kapetsky and Profeti (1999). Fishponds are small enclaves of calm water surrounded by dykes on all sides. A dyke is an earthen wall whose thickness ranges approximately from half a metre to several metres, and whose 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 8).

FIGURE 8
Interaction of radar beams with dykes and water surfaces on a group of fishponds



The position of the dykes in the image is shifted along the cross-track direction and toward the sensor. The apparent dimensions of the dykes in the image do not correspond to the real ones.

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)

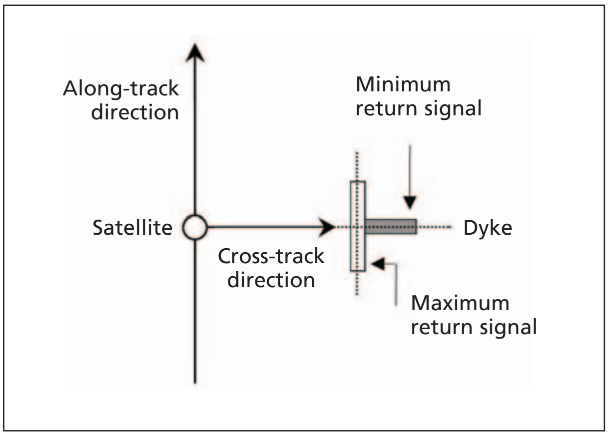


As shown in the figure, the radar signal bounces off of both planar surfaces and is reflected directly back toward the antenna. The pixel corresponding to the corner reflector has a high value, and thus fishponds appear as dark areas surrounded by bright, elongated structures.

Due to the peculiar acquisition geometry, the position of a corner reflector in a SAR image does not correspond exactly to the orthogonal projection of the dykes on a map. The position of the dykes in the image is shifted along the scanning (cross-track) direction and toward the sensor, and their apparent extension does not correspond to the actual one. Actually, the SAR signal of each pixel is obtained by averaging the radiation reflected back by the various surfaces inside the area corresponding to the pixel. Thus, if the imaged area contains a small but highly reflective object, the average backscattered radiation is almost equal to the single contribution of the object. As a result, the pixel assumes a high value and the dyke appears to be as big as the entire pixel. The multiple reflection on the dyke may also spread the high return signal to the surrounding pixels, increasing their values as well. Therefore, the extension of a dyke may appear larger in a SAR image than in reality.

The return signal of elongated objects varies also as a function of the angle between the object and the cross-track direction (Figure 9). 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.

FIGURE 9
Return signal as a function of the angle between a dyke and the cross-track direction



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 (Figure 10). 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.