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

Authors: Carlo Travaglia[1], Giuliana Profeti[2], José Aguilar-Manjarrez[3] and Nelson Lopez[4]

1 FAO, Environment and Natural Resources Service, Rome, Italy (retired); carlo.travaglia@libero.it
2 Consultant, Florence, Italy; g.profeti@nonsologis.it
3 FAO, Inland Water Resources and Aquaculture Service, Rome, Italy; Jose.AguilarManjarrez@fao.org
4 Bureau of Fisheries and Aquatic Resources, Manila, the Philippines; nlopez@bfar.da.gov.ph

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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.

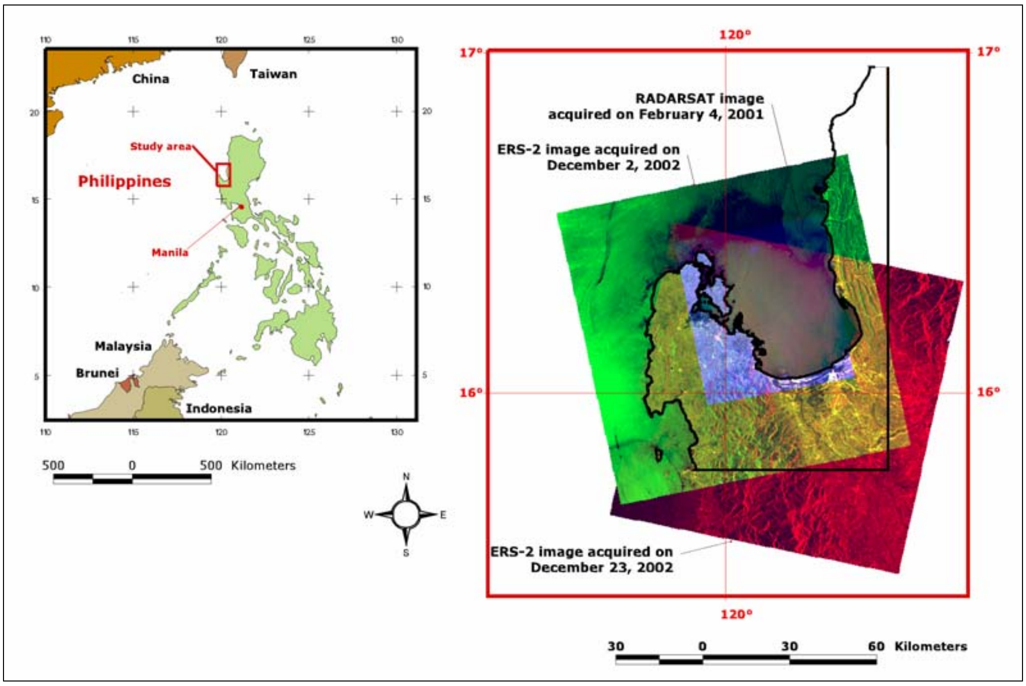

Figure 1: The study area and the zones covered by the satellite data.

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).

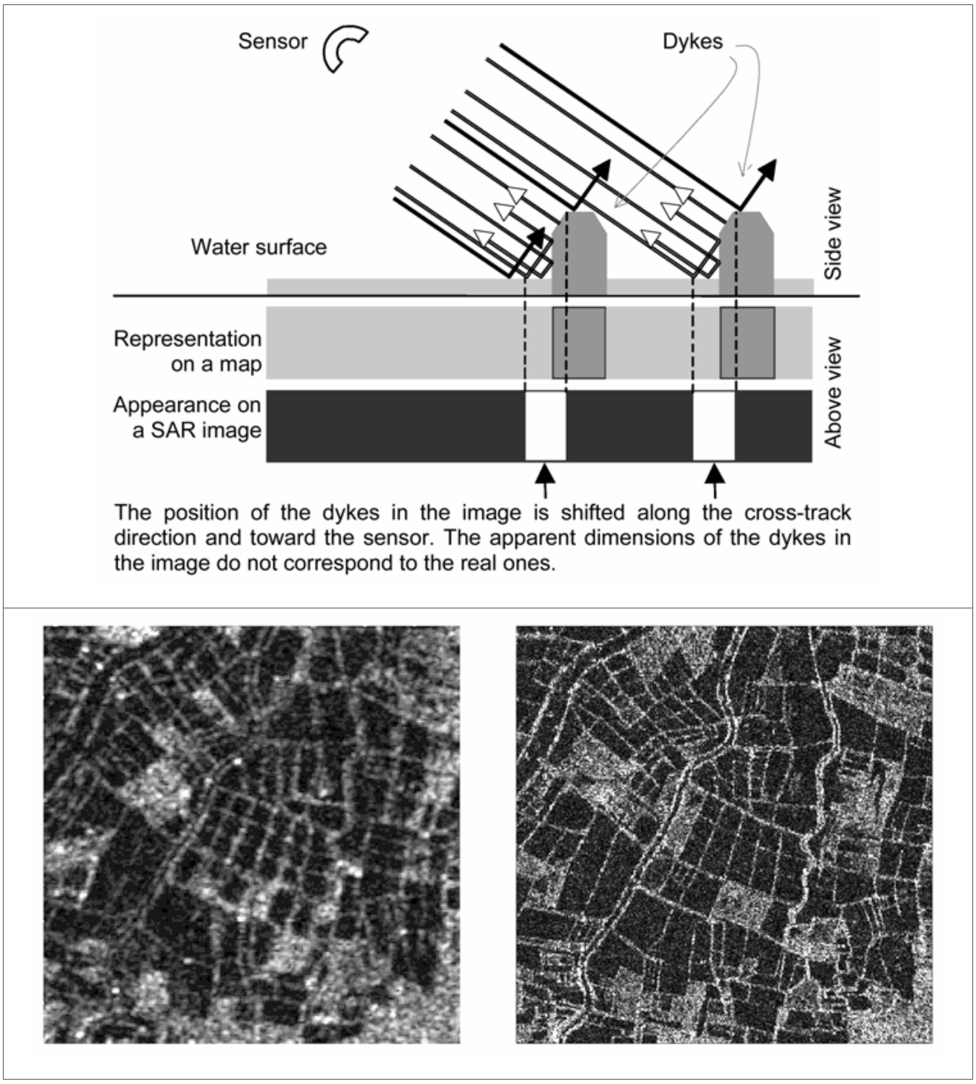

Figure 2: Above, interaction of radar beams with dykes and water surfaces on a group of fishponds. Below, appearance of fishponds in the ERS-2 SAR image of 2 December 2002 (left) and in the RADARSAT-1 SAR image of 4 February 2001 (right).

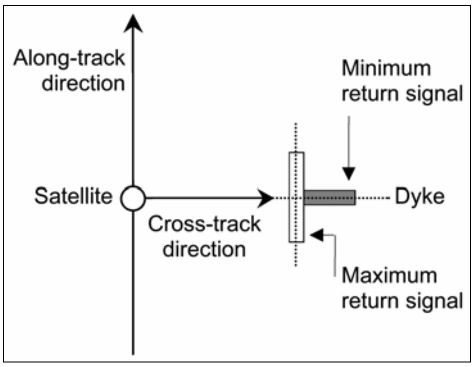

Figure 3: Return signal as a function of the angle between the dyke and the cross-track direction

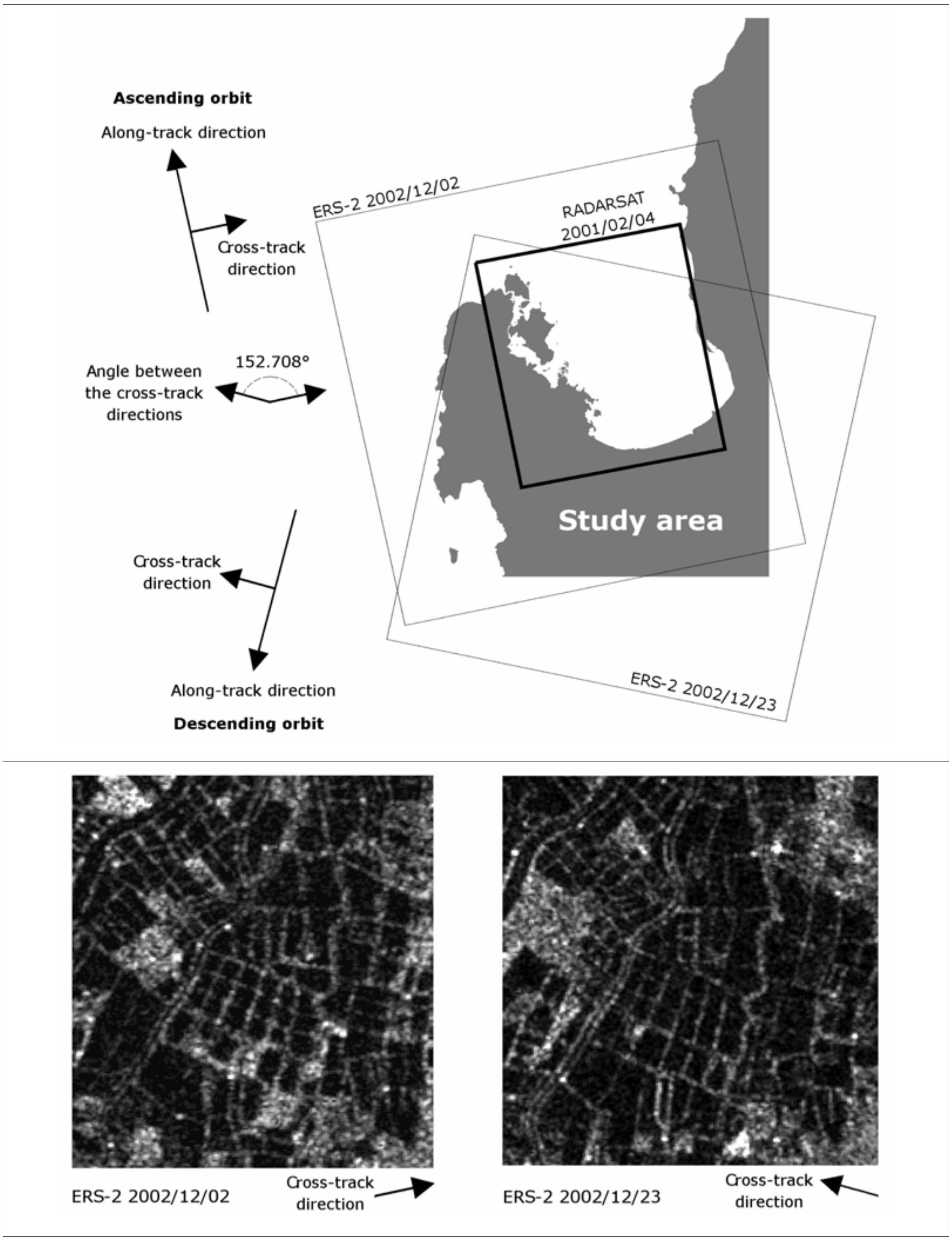

Figure 4: Above, the angle between the scanning directions in the SAR data used in the study. Below, differences in the fishpond pattern due to the diverse scanning directions in the ERS SAR images acquired on ascending and descending orbits.

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.

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