Title: INVENTORY AND MONITORING OF SHRIMP FARMS IN SRI LANKA BY ERS-SAR DATA

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ESA article: http://www.esa.int/export/esaCP/ESAAQWZ84UC_Protecting_0.html

Application Tool: Remote Sensing.

Main Issues Addressed: Suitability of the site and zoning.

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 shrimp farms is essential for decision-making on aquaculture development, including regulatory laws, environmental protection and revenue collection from a government viewpoint. Inventory and monitoring also are important from the commercial viewpoint for a variety of management and development decisions including site selection and risk analysis.

In order to be timely and useful, identification and monitoring of shrimp farms demands an accurate, fast and mainly objective methodology. Synthetic aperture radar (SAR) data are uniquely useful not only for their inherent all-weather capabilities (very important as shrimp farms occur in usually cloudy areas) and frequent coverage, but mainly because the backscatter from surrounding dykes allows for recognition and separation of shrimp ponds from all other water-covered surfaces.

Main Environments: Brackishwater.

Culture Systems: Ponds.

Organism Divisions: Crustaceans.

Genera and Species: *Penaeus mondon*, tiger prawn.

Target Country: Sri Lanka.

Target Audience: Aquaculture planners in government agencies; shrimp farming trade organizations, shrimp farmers.

Duration of the Study and Year Begun: Four months; 1999 (see Table 10).

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 Senior Fishery Resources Officer); assisted with the design of the study, carried out the ground verification mission; part-time for the duration.

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

Sri Lankan mariculture and GIS specialists (3) who played a key role in ground verification (see Acknowledgements); part time.

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Introduction

Perspective on shrimp farming

Global Importance of Shrimp Farming

Global farmed shrimp and prawn production amounted to 932 000 t in 1995 compared with some 170 000 t in 1984. Production has plateaued since 1991. Eighty-seven percent originated in Asia.

Constraints on the Further Development of Shrimp Farming

Despite the rapid growth of the industry, there have been setbacks due to diseases and due to the growing awareness of the environmental and social impacts of shrimp farming. Much of the debate has focused on the sustainability of shrimp farming. There is a trend for discussion on principles, the development of guidelines and the need for better management practices (FAO, 1998). It has been recognized that shrimp farming can be made more sustainable. Impacts can be reduced in a number of ways including through better regulatory and planning processes at State level. Key considerations are the siting of shrimp farms and monitoring their development.

State of shrimp farming in Sri Lanka (Northwestern coast)

Shrimp farming began in Sri Lanka in the early 1980s. Farming of the black tiger prawn, *Penaeus monodon*, was a successful and lucrative venture until major disease outbreaks occurred in the late 1980s (Wijepoonawardena and Siriwardena, 1995). Although the main cause for these outbreaks was thought to be the introduction of an exotic viral pathogen, uncontrolled proliferation of farm operations and related aquatic environmental implications appear to have made a direct contribution. Similarly, lack of planned development was identified as one of six constraints on shrimp farming and suitable locations in the NW were said to be almost saturated (Piyasena, 1996).

Currently, the shrimp culture sector in Sri Lanka is facing many of the problems previously encountered in other countries. The technical knowledge base of the majority of the shrimp farmers is very low and becoming increasingly so, as more small-scale farms are developed. Shrimp farming is still relatively small scale in Sri Lanka with a total area of approximately 2600 ha according to Funge-Smith (1998). These farms can be broken down by surface area as shown in Table 1.

The majority of the unregistered farms have encroached into reserved areas and are small farm operations – their size generally being below 2–3 ha. Farms over 4 ha are required to fulfil Initial Impact Investigation or Environmental Impact Assessment; small farms are exempted from this and this has contributed to the proliferation of small illegal operations.

Table 1 Size and relative occurrence of shrimp farms in Sri Lanka (Funge-Smith, 1998).

Area (ha)	**% of total area**
> 20	32
10 - 20	9
4.5 - 10	15
2 - 4.5	10
< 2	6
Unregistered farms	28

Small farms are usually owner operated and do not have a high level of technical input. There appears to be some form of technical service available whereby farmer groups are visited by local consultants. Large farms have well trained managers – often with overseas experience.

It is the lack of accurate information available to the farmers that results in inappropriate farming techniques, disease and production losses.

Plans are currently underway to develop shrimp farms in other parts of the country, utilizing seawater abstracted from the sea (full salinity) and not the brackishwater usually found in the Northwest Province lagoon systems. Culture in full strength seawater is possible providing a regular water exchange regime is practiced. Alternatively culture should only take place during the monsoon or rainy season, to prevent excessive salinity in the ponds. Before these developments proceed further, it is important to establish the principle factors underlying the disease problems in the Sri Lankan shrimp industry.

There is also the consideration that the Northwest Province may provide much of the country’s broodstock, and the development of shrimp farms in this area would certainly increase the risk of contamination of the broodstock supply.

Objective of the study

The main objective of this study has been to demonstrate, under operative conditions, and in support of TCP/SRL/6712 “Revitalization and Acceleration of Aquaculture Development” the usefulness of high resolution SAR data for the inventory and monitoring of shrimp farms, in view of developing and field testing adequate methodologies for future use in similar environments elsewhere.

To achieve this objective in the Sri Lanka case study, ERS SAR satellite data, acquired in 1996, 1998 and 1999, have been processed for shrimp farms inventory, and the resulting information has been compared to substantiate changes and trends in the development of shrimp farms.

Basically, the Sri Lanka Government requires up to date information on the spatial distribution of shrimp farms in order to enforce development regulations and in order to ensure a productive environment for shrimp farming with the least impact on other uses of land and water resources.

This study is timely because it coincides with two related activities, one of which is the zoning of aquaculture in Sri Lanka, and the other on disease prevention and health management in shrimp farming, both of which are FAO Technical Cooperation Programme projects.

Study area

The area under examination occurs along the western coast of Sri Lanka, north of Colombo (Figure 1 and Figure 2), approximately from 8° 23' to 6° 50' North Latitude (Table 2), covering a strip 30 km wide at its maximum and 172 km long. It is a coastal flatland, characterized by a series of inland lagoons and lakes (from North to South: Puttalam Lagoon, Mondal Lake and Chilaw Lake) connected by channels, meandering rivers and creeks.

The vegetation existing prior to the development of shrimp farms is reported in the 1984 topographic maps as being mainly composed of low forest, grassland and mangroves; the main agricultural crops were rice and coconuts.

Shrimp farms, which cover extensive portions of this area, can be subdivided into two major groups: industrial and artisanal.

Industrial shrimp farms (Figure 3) cover usually large areas with individual shrimp ponds arranged in an orderly way, rectangular in shape and all of the same size, with average dimensions of 30 x 50 metres. Industrial shrimp farms are usually surrounded by high walls or fences, in consideration of the considerable value of their product. Conversely, artisanal shrimp farms cover relatively small areas, the shrimp ponds are of various sizes and, often, of various shapes, and dykes surrounding individual ponds are less prominent than that occurring in industrial shrimp farms. Further, the shape of the complex is somewhat irregular as it exploits natural areas along creeks and canals.

The study area is fully covered by two ERS SAR frames (Table 3). For monitoring purposes four different data sets were studied, acquired respectively by ERS 1 on 18 April 1996 and by ERS 2 on 3 July and 16 October 1998 and 5 March 1999.

The ERS SAR GEC (geocoded) data have a spatial resolution of 12.5 x 12.5 metres. Each scene covers an area of 100 x 100 km. Nominal frequency of data acquisition over a given area is of 35 days. The adopted projection is UTM (Zone Number 44N, spheroid and datum WGS84).

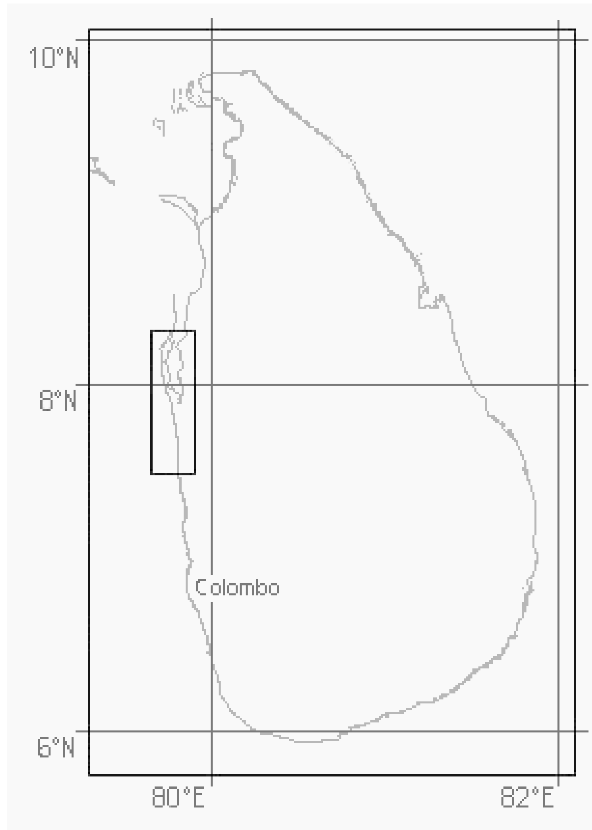


Figure 1 Study area (geographic reference grid).

Table 2 Coordinates of the study area.

UTM 44N, WGS84	Upper left corner	Lower right corner
Northing (y)	928340	755690
Easting (x)	352219	382007

Table 3 Satellite data used in the study.

ERS SAR GEC	Orbit/Frame	Acquisition date
ERS 1	24885/3465 and 3447	18/04/1996
ERS 2	16735/3465 and 3447	07/03/1998
ERS 2	18238/3465 and 3447	16/10/1998
ERS 2	20242/3447	05/03/1999

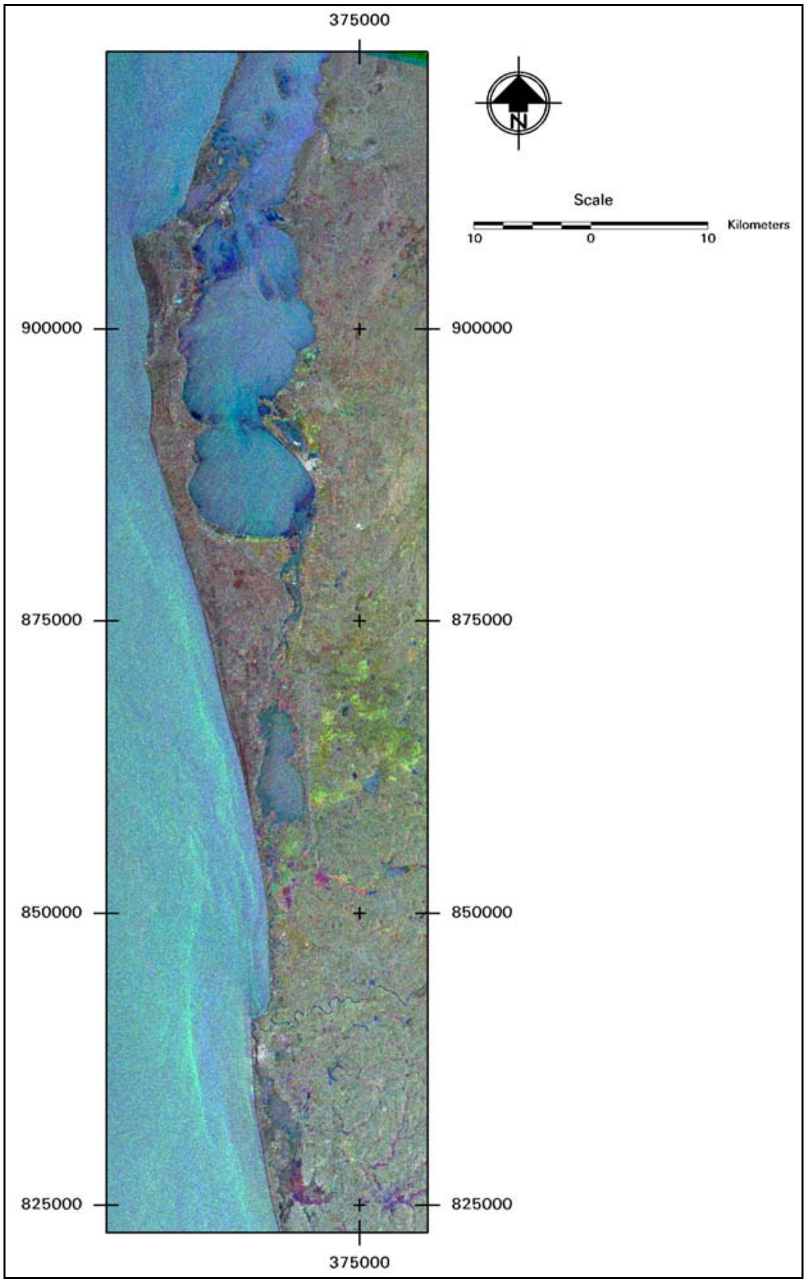


Figure 2 False colour composite of three ERS SAR images of the study area.
Red: 18/04/96, Green: 03/07/98, Blue: 18/10/98.

Materials and Methods

Shrimp farm mapping by imaging radar

The identification of shrimp farms (Figure 3) on SAR images is based on several elements: the signal received from the water surface of the ponds and from their surrounding dykes, the shape of the individual ponds, the pattern of groups of ponds and the relative direction of the dykes vis-à-vis the incoming radar beam. The location of shrimp farms is also typical, thus the analysis of their position and of the former land use of the area is necessary to verify the identification.

All these elements are discussed in the following sections.

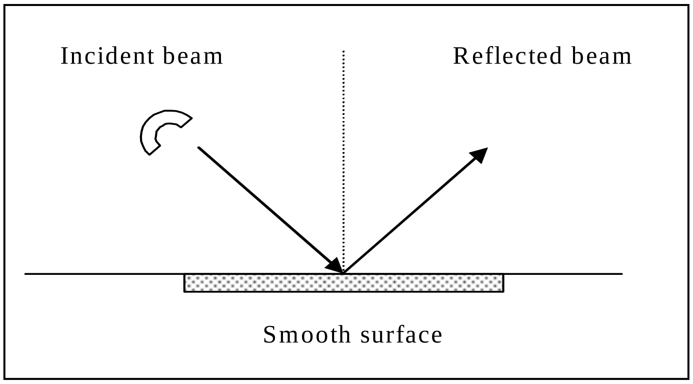
Figure 3 Industrial shrimp farm (south of Chilaw Town).

SAR signal of ponds and dykes

Water-covered surfaces, such as shrimp ponds, are easily identifiable on SAR images due to their characteristically low response, resulting in a very dark grey level. The reason for the low response of water-covered surfaces, as well as of other very smooth surfaces, lies in the wavelength employed and in the peculiar acquisition geometry of SAR images.

The ERS SAR system operates in the C-band ($\lambda \cong 5.6$ cm), and the angle between the perpendicular to the imaged surface and the direction of the incident beam is approximately 23°. According to the Rayleigh criterion, a surface is considered smooth if the mean height of its structure is smaller than the incident wavelength. Small water bodies generally satisfy this condition, and according to Fresnel's Law, they reflect all the incoming radiation at an angle equal to the incidence angle, thus away from the satellite antenna (Figure 4). Consequently, the signal received from a small water body approaches zero, and the water body is visualized as a dark grey surface (Figure 5).

The identification of low-reflecting surfaces in an image is a simple task. Unfortunately, a low response is obtained by all calm water bodies, such as small lakes, reservoirs and flooded areas. The problem in identifying shrimp ponds on SAR images is then focused on separating the various kinds of low-reflecting surfaces by means of their peculiar characteristics of shape and pattern, and the characteristics of their neighborhood.



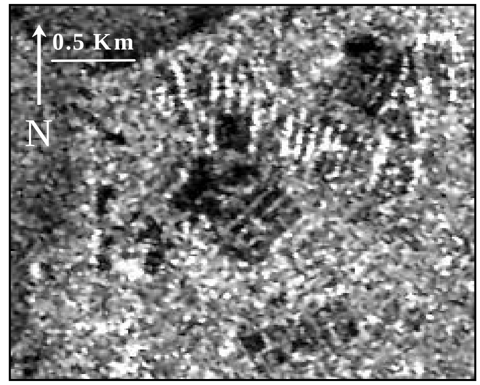


Figure 4 Interaction of a radar beam with a smooth surface.

Figure 5 ERS SAR, 18/04/96: shrimp ponds at Vidatamunai, Puttalam Lagoon.

Shrimp ponds, unlike other water bodies, are surrounded by dykes. 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. The surface of a dyke can be considered smooth; the radar beams interaction with the dyke depends on their relative position.

If the long axis of a dyke is perpendicular to the cross-track direction, the resulting radar beam paths are shown in Figure 6. The radar beams that reach the upper part of the dyke are reflected in the direction opposite to the sensor, giving no return signal.

The beams which reach the vertical part of the dye are reflected towards the water surface of the pond first, then back to the sensor, generating a very strong return signal.

The same happens to the beams which hit the water surface near the dyke: they are first reflected towards it, then back to the sensor. If part of the dyke is inclined, the beams, which hit it, are reflected directly into the sensor, generating an even stronger return signal.

Another consequence of this peculiar imaging geometry is that the position of the dyke in the image appears to be shifted towards the sensor (layover effect: Figure 6).

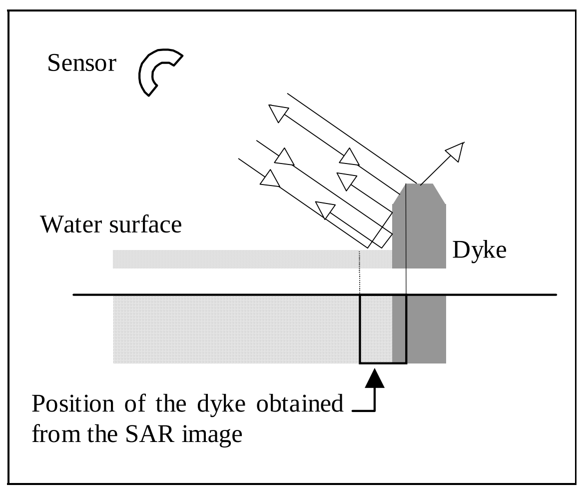


Figure 6 Interaction of radar beams with a dyke.

The value associated with an ERS SAR image pixel (digital number, DN) is given by the average signal received from the corresponding surface on the ground. When a portion of the ground contains a small but highly reflective feature, the average signal is almost equal to the imaged feature, which appears then to be as big as the entire pixel. The object has "saturated" the pixel's value. This effect is caused by the dykes as well. The dykes are long but narrow structures, thus the DN value of a pixel is made up by the return signals from both a portion of the dyke and its surroundings. However, a dyke's return signal is so strong in comparison with the low signal of the water-covered ponds that the resulting value of the pixel is very high.

The multiple reflection effect spreads the high return signal to the surrounding pixels, increasing their values as well. Therefore the dyke, when perpendicular to the incoming radar beam, is easily identified in the SAR image as a white stripe (Figure 5) composed of several adjacent pixels, thus thicker than in reality.

Paddy fields are surrounded by smaller and lower dykes, which do not generate the same effect and consequently are not identifiable in SAR images.

The multiple reflection effect discussed above and its consequences take place on the portion of the dyke that directly faces the incoming radar beam. Consequently, the intensity of the return signal depends on the angle between the cross-track direction and the direction of the longer side of the dyke (Figure 7).

When a dyke is perpendicular to the cross-track direction, all the corresponding pixels have a very high return signal, as discussed previously.

When the angle between the longer side of the dyke and the cross-track direction decreases, the multiple reflection effect decreases as well. The resulting signal is weaker, and the dyke's pixels are displayed as darker grey in the SAR image.

Finally, when a dyke is parallel to the cross-track direction, it barely interacts with the radar beams, and is thus characterized by very dark grey tones in the image.

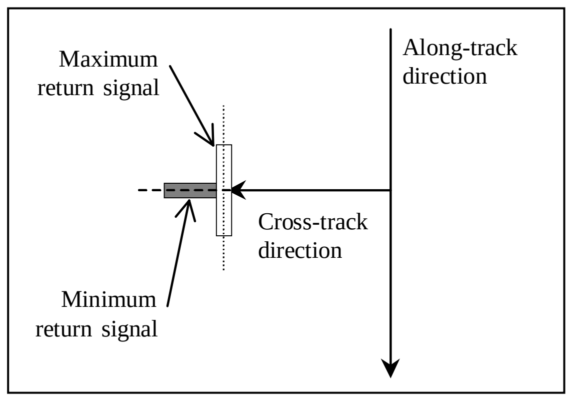


Figure 7 Return signal as a function of the angle between a dyke and the cross-track direction.

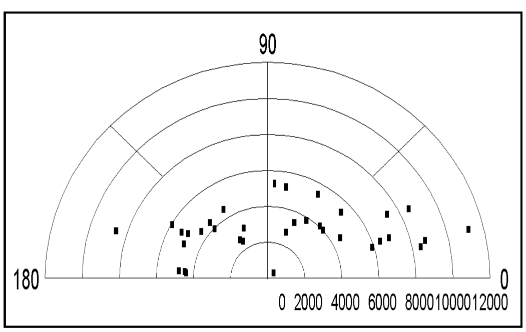


Figure 8 Dyke's average values (DN) vs bearing (deg.)

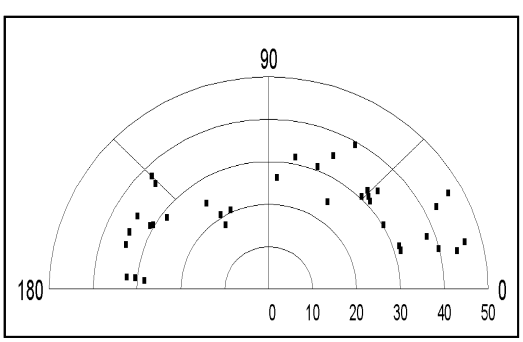


Figure 9 Dyke's average thickness (m) vs bearing (deg.)

It has been observed previously that the dykes perpendicular to the cross-track direction appear to be thicker than they really are, due to the saturation effect. Dykes positioned at smaller angles from the cross-track direction have lower return signals; the saturation effect decreases and their apparent thickness decreases as well. When the angle between a dyke and the cross-track direction is zero, i.e. the dyke is parallel to the cross-track direction, it is barely visible in the image.

Both of these effects are evident in the ERS 1 SAR image of 18 April 1996 (Figure 5).

The average DN values and thickness of 35 dykes in this image have been plotted in Figure 8 and Figure 9. The two graphs show the effects explained above.

The along-track direction of the satellite during the acquisition was 192.5 deg. North.

Dykes parallel to the along-track direction (i.e. bearing 12.5 deg. North) look very bright and large in the image. At increasing angles between the dykes and the along-track direction, the dykes appear grayer and thinner. Finally, dykes perpendicular to the along-track direction (i.e. bearing 102.5 deg. North) are not visible in the image.

The most important consequence of the dykes' intensity and thickness variations with bearing is that they cannot be identified through automatic or semiautomatic image processing procedures, because both these procedures identify surfaces only if their characteristics are constant in the entire image.

From the above discussion it follows that automatic or semiautomatic SAR image analysis allows identification of all water-covered surfaces, including shrimp ponds, and high reflective surfaces, including the dykes positioned perpendicularly to the sensor's cross-track direction. It is then necessary to use visual interpretation techniques to recognize the shrimp ponds among these surfaces. These techniques, applied by an operator, take into account the dykes' variations in intensity and thickness with bearing, plus shape and pattern of ponds and dykes. The latter elements are discussed below.

Size, shape and pattern of ponds and other water-covered surfaces

The characteristics of all kinds of water-covered surfaces in the study area must be analyzed to infer the peculiarities in the appearance of ponds and groups of ponds in SAR imagery, and define both the identification criteria and the minimum identifiable pond size.

As indicated, two kinds of shrimp farms are present in the study area (Figure 10): industrial and artisanal shrimp pond systems.

- *Industrial shrimp farms* are generally large, rectangular in shape and associated in a pattern of regularly alternating dykes and similarly sized ponds.
- *Artisanal shrimp farms* are generally smaller in size, less regular in shape and form groups without a regular pattern; also, their surrounding dykes are less evident.

Both kinds of shrimp farms are located along rivers, canals and creeks.

Other water-covered features present in the study area are reservoirs, lakes, rice paddies and flooded surfaces of various kinds.

Lakes and reservoirs (Figure 11) cannot be misidentified as shrimp ponds because they are large, isolated features with irregular shape. Moreover, part of their surface may be roughened by wind, or covered by vegetation; in these cases they appear noticeably less dark than ponds or paddies.

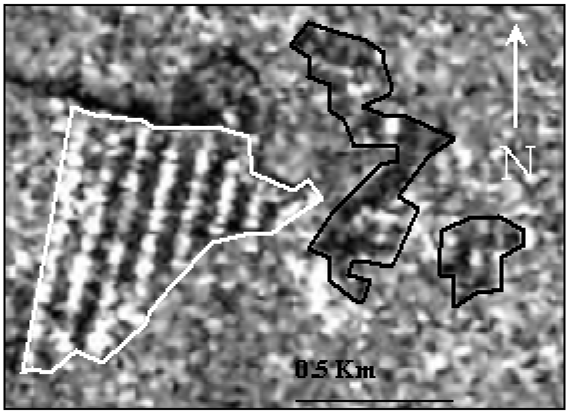


Figure 10 Industrial and artisanal shrimp farms.
ERS 1 SAR, 18/04/96

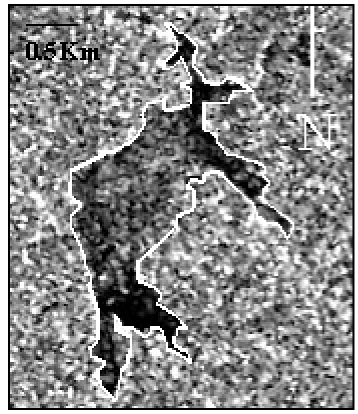


Figure 11 A reservoir.
ERS 1 SAR, 18/04/96

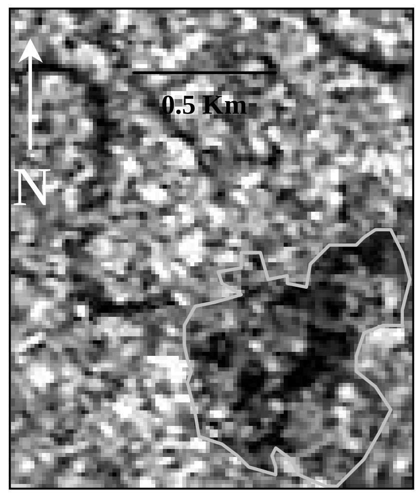


Figure 12 Rice paddies and their appearance on 18/04/96 ERS 1 SAR image (grey-outlined area)

NEXT PAGE