1. Introduction

1.1 BACKGROUND: 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.

Inventory and monitoring of shrimp farms are essential tools for decision-making on aquaculture development, including regulatory laws, environmental protection and revenue collection. 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 that satellite imaging radar was the only tool available for achieving good results. Synthetic Aperture Radar (SAR)[1] 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, 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 such as Landsat or SPOT, 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.

Apart from the advantages reported previously (all-weather capabilities and easy discrimination of shrimp farms from all other water covered surfaces), employing SAR data for shrimp farms inventory and monitoring provides two more benefits.

The first is timeliness, as satellite data are acquired regularly and this allows for the extraction of up-to-date information. Results of the pilot study indicate that shrimp farming is growing at a very rapid rate in northwestern Sri Lanka and that the surface is much more extensive than reported in official data. The second, an important advantage over traditional surveys, is that the resulting digital radar maps can be incorporated into an existing Geographic Information System (GIS). Once incorporated into the GIS, the shrimp pond locations can be evaluated in terms of a number of characteristics of site suitability and also with regard to prior uses of the land. In this way the development of shrimp farming can be better planned and regulated in a more rational way than is possible without such information. In this regard, it is important to note that such information is of use not only to government, but valuable also to associations of commercial shrimp farmers whose underlying

[1] See Glossary in section 5 for a complete definition of SAR.

purpose is to maintain a dependable supply of good quality products at competitive prices.

The need for shrimp farm mapping is both qualitative and quantitative. In this regard, the results of the pilot study show that the location of commercial shrimp farms can be accurately obtained, and their collective size estimated with satisfactory results. It is sometimes difficult to estimate the area coverage of individual, small sized shrimp farms, but it is generally possible to estimate with good approximation the area coverage of a cluster of shrimp farms.

The results of the study are reported in Table 1 which indicates the rapid expansion of the shrimp farm industry in northwestern Sri Lanka, which has increased its area coverage by 44.1 percent in less than three years. Figure 1 shows the expansion of shrimp farms in the Dutch Canal test site.

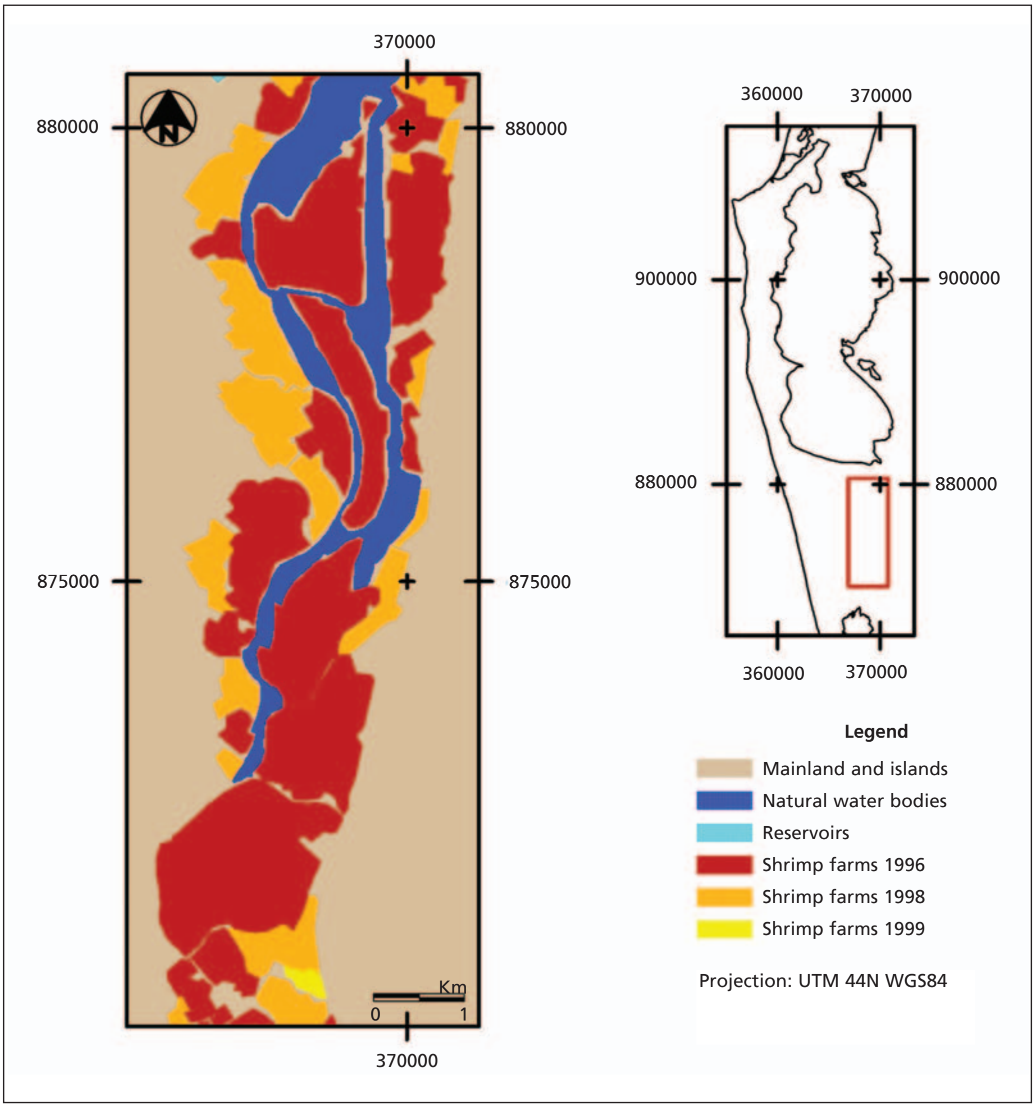
TABLE 1

Total surface covered by shrimp farms, Sri Lanka study (Travaglia, Kapetsky and Profeti, 1999)

Date of image acquisition	Area *(km^2)*	Increase *(%)*
18 April 1996	61.3978	-
16 October 1998	86.5289	40.9
5 March 1999	88.4605	2.2
Difference 1999–1996	**27.0627**	**44.1**

FIGURE 1

Shrimp farms in the Dutch Canal test site, Sri Lanka (Travaglia, Kapetsky and Profeti, 1999)



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.

To disseminate this new approach to potential users, a technical report was prepared by Travaglia, Kapetsky and Profeti (1999), and is available on the Web at http://www.fao.org/sd/EIdirect/EIre0077.htm.

1.2 OBJECTIVE OF THE PRESENT STUDY

The pilot study in Sri Lanka demonstrated the usefulness of Synthetic Aperture Radar (SAR) satellite data for inventory and monitoring of shrimp farms, and in general, of fishponds with high accuracy. The satellite remote sensing approach was found to be economically viable, as the value of shrimps more than justifies an accurate inventory and monitoring of the development of the farms.

Although hardware (PC-based digital imagery analysis systems) and software (ERDAS, ENVI, ArcView or equivalent) are now usually available in remote sensing agencies and laboratories, the methodology requires a good background in imaging radar theory and a considerable practice in handling and processing SAR data. However, as indicated, only satellite imaging radar (SAR) allows for the accurate mapping of fishponds.

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 fishpens, fish cages and fish traps.

Therefore, the objective of the present study is 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. It is aimed at the general fisheries and aquaculture public, governmental administrators and planners and remote sensing and GIS specialists.

The selection of a test area in which to conduct the study was the first problem to be solved: the area needed to include all of the structures of interest; furthermore assistance from a local team was necessary for baseline information and field checking of the results. The Lingayen Gulf, in northern Philippines, where all structures under study are present was thus selected as test area and the assistance to this exercise by the Bureau of Fisheries and Aquatic Resources of the Philippines was secured.

1.3 DESCRIPTION OF THE TEST AREA

Lingayen Gulf is located in the northwestern coast of Luzon Island, the Philippines at coordinates between 16° and 17° North latitude and 119° and 121° East longitude. The test area is a little smaller, being the area covered by the satellite data used in the study (Table 2 and Figure 2).

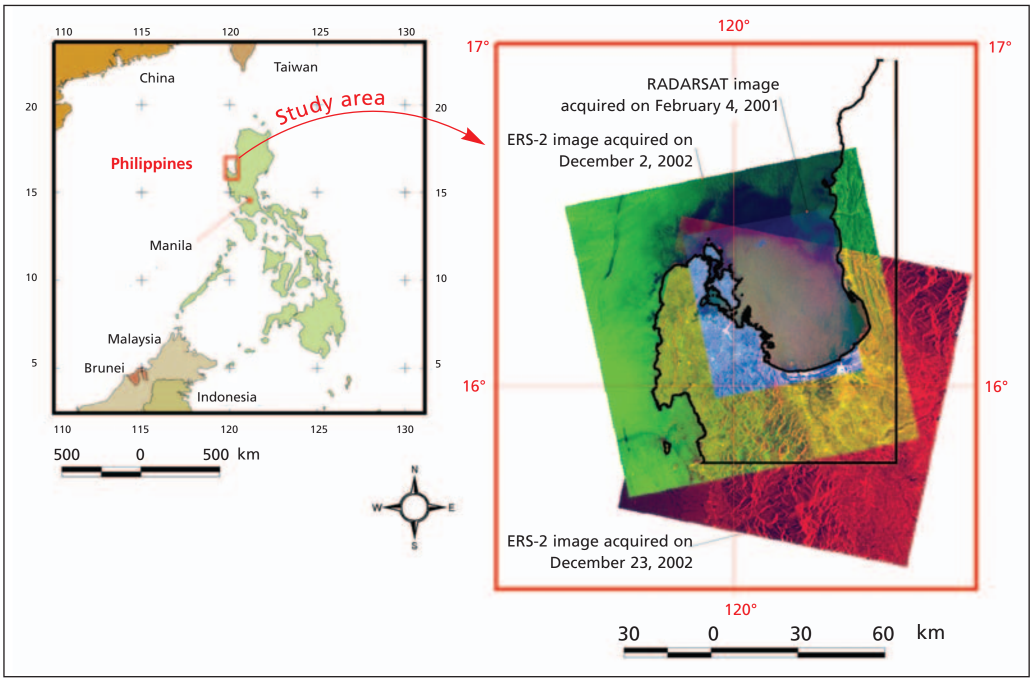
The gulf is bounded on the east by the steep slopes of the Central Cordillera, in the south by the northern portion of the Luzon Central Plain and on the west by low hills, the northernmost features of the Zambales Mountains, continuing into the sea with the several islands. The gulf is a semi-circular embayment enclosing an area of approximately 2 100 km^2 with 160 km of coastline from Cape Bolinao to Poro Point.

The northern portion of Luzon Central Plain is a vast alluvial lowland drained by several rivers, of which the Agno River, with its large catchment of more than 5 000 km^2, is the most important. The area experiences severe floods during wet season mainly due to overflow by the Agno River, with extensive damage to fisheries and agricultural crops.

TABLE 2
Coordinates of the study area

Geographic, Ellipsoid Clarke 1866, datum Luzon	Upper left corner *(decimal degrees)*	Lower right corner *(decimal degrees)*
Latitude	17.00	15.75
Longitude	119.75	120.50

FIGURE 2
The study area and the zones covered by the satellite data



Five major rivers drain into the gulf: Bauang and Aringay, flowing from the Central Cordillera; and Patalang-Bued, Dagupan and Agno flowing northward from the Central Plain but originating in the Central Cordillera. These rivers affect the physico-chemical characteristics of the gulf. Sediment loads of Agno and Patalan-Bued Rivers include sediment and contributions from the mines located in Benguet on the upstream segment of the rivers.

Lingayen Gulf is a major area for capture fisheries, aquaculture and coastal tourism. From 1980 to 1984, an average annual catch of 2 000 tonnes was landed by commercial trawlers, and a yearly mean of 6 000 tonnes by small-scale fishermen. The gulf ranked second highest nationwide in brackishwater pond yield, with a fish production of over 1 tonne/ha in 1984 and 1985. Most recently the gulf supplies almost one-third of the farmed milkfish (*Chanos chanos*, Forsskål, 1775) to Metro Manila. Fish production increased since the early 1990s when sea cage farming in pen and cages were allowed by the coastal municipalities. Approximately fifty tourist-oriented establishments are located along the 160 km coastline of the gulf, or about one lodging place for every 3 km stretch of shore (BFAR, 2001).

But like most of the country's coastal waters, the gulf is beset by complex problems which make multisectoral planning necessary. Capture fisheries exert very intense pressure on the gulf's fish resources. With over 12 000 fishermen and 7 000 boats in the 18 coastal municipalities and cities surrounding the gulf, catch per unit effort (CPUE) has reached a suboptimal level of less than 1 kg/fisherman/day. As a result, small-scale fishing has become the most marginal occupation in Lingayen Gulf. The use of explosives and chemicals to augment the catch has contributed to rapid habitat degradation and diminution of fish stocks. Pollution of the gulf with silt, domestic and industrial waste, including mine tailings, has caused deterioration of the environment and dwindling productivity, particularly in the aquaculture industry (BFAR, 2001).

Aquaculture in the Lingayen Gulf started as early as 1920s by converting privately owned mangrove areas, nipa and rice land into brackishwater fishponds. In 1986 there were a recorded 16 000 hectares fishponds occurring in La Union and Pangasinan, the two coastal provinces of the gulf.

The aquaculture industry in Lingayen Gulf historically established as early as 1920s expanded into mariculture with the introduction of seafarming technologies in seaweeds and bivalve culture. It then proliferated in the early 1990s when the Fisheries Code of the Philippines (Republic Act 8550) devolved the management power of the municipal waters to the local government units (under the city and municipal administration). By virtue of local fisheries ordinances, individual municipalities and cities within the gulf allotted areas for mariculture (in pens and cages) and fish traps (fish corrals) in designated zones. However, poor planning and lack of effective monitoring, have caused depletions of corals, recurrent fish kills and eutrophication of the gulf water. Brackishwater fishponds are affected by pollution brought about by sludge and sediments formation from the substrates of fish pens, fish traps and fish cages which are flushed by the current along the riverine system of the gulf. On the other hand, fish cages, fish pens and fish traps operators along the bay and estuarine areas of the gulf, blame the brackishwater fish pond effluents to have caused the mass mortalities of farmed and wild fishes in the coves of the gulf.

To date however, there are no available baseline statistical data as to what amount of the total brackishwater areas are still engaged in the traditional fishpond farming and how many cages or pens are operational in each particular city or municipalities. Production data from aquaculture in the province, although being monitored by the provincial offices of the Bureau of Agricultural Statistics are still inaccurate and require updating.

There has been no previous study or inventory records of existing operational fish pens and marine seacages, except the registered records of present operators in the Gulf by the Local Government Units (LGUs) indicating an increasing numbers of fish pens and fish cages which are concentrated mostly along the province of Pangasinan compared to previous years (BFAR, 2001).

During the course of the field survey for the present study, out of the fishpond areas verified, roughly 80 percent were non operational during the time of survey and were either found to be idled due to losses by floods, water management problems due to siltation and pollutions resulting in fish kills due to oxygen depletion, or were just waiting for the best farming season (average: 1–2 crops per year). Some farms, particularly those close to urban areas are presently converted into commercial lots, as in the case of Barangay Salapingao where previous fishpond areas are now reclaimed as residential areas. The presence of numerous and continuously increasing number of cages, pens and fish traps within the gulf areas indicates that seacage farming and artisanal fishing are now the preferred fisheries industry in the entire locality. Actually, a fish pen or a fish cage costs about one-tenth of a fishpond and may produce three times more.

1.4 DESCRIPTION OF THE STRUCTURES: FISH PENS, CAGES AND TRAPS

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 (Beveridge, 1987; Muir, 1995; Shehadeh, 2002).

Fish pens in the Lingayen Gulf are made up of nets on all sides and utilize the sea bed as the bottom enclosure or often are provided with extended bottom nettings (Figure 3). A pen is usually supported by fixed rigid frameworks of coconut posts or bamboo poles and wooden frames, making it a stationary farming structure. The bulk

FIGURE 3
Fish pens in Lingayen Gulf (Photo: BFAR/N.A.Lopez, 2003)

of mariculture activities using fish pens is concentrated in the coastal and inland waters of Bolinao, Dagupan and Binmaley in Pangasinan and Aringay in La Union. The number of fishpens in these municipalities in 1996 amounted to 685 units spread across an area of 41.1 hectares. The surface enclosed by fish pens varies from one-fourth of a hectare to 2 hectares or more (BFAR, 2001).

The most common species for culture is milkfish (*Chanos chanos*). At present, fishpen operators need to extend their culture period from 5 to 6 months in order to produce milkfish of marketable size (=500 g/piece). In previous years, three months were sufficient to produce marketable sized fish. Harvest frequency has been reduced from 4 to 3 or 2 cycles per year. The major reason is the deteriorating water quality from pollution caused by low water exchange resulting from high stocking densities, excessive feeding and the unregulated establishments of these structures in most of the coastal municipalities.

It has been also noted most recently that the excessive use of commercial formulated feeds for milkfish in fish pens has drastically contributed to the formation of massive sludge deposits on the substrate that decompose to a deadly form of hydrosulfates contributing to the mass mortalities of fish stocks during tidal overturns and inclement weather conditions. As the pens are stationary and fixed in shallow areas, unlike cages which are positioned in deeper portions and can be moved, most fish kills do occur in fish pen belt areas rather than in fish cages. Both farming structures, however, are stocked with high densities of fish and require daily intensive feeding which also pollutes the water environment.

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 (Beveridge, 1987).

Fish cages in Lingayen Gulf have evolved from the old traditional fixed cage consisting of a net bag supported by bamboo posts driven into the bottom of a lake or river for fish fattening or grow-out purposes to floating net cages using suspended bottom net enclosures supported with bamboo poles, wooden planks, floats and fixed anchors. With the innovation of milkfish broodstock cages, steel pipes supported with styrofoam floats and concrete anchors were later designed for longer use. Most recently, imported and locally modified Norwegian cages are employed for the mass culture of milkfish in the gulf (Figure 4). 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).

FIGURE 4
Fish cages in Lingayen Gulf (Photo: BFAR/N.A.Lopez, 2003)

In 1995, when mangrove conversion into fishponds was prohibited, most fish farmers engaged themselves into mariculture of milkfish (which were traditionally cultured in fishponds) utilizing fish cages and fish pens in rivers (estuarine areas) and open sea (within the gulf area) since they have no other alternatives to expand their milkfish farming activities. Most recently, some farmers diversified their mariculture practices not only in milkfish grow-out, but also in fattening and intensive farming of groupers and other high valued commercial species in pens and cages.

As with fish pens, the main farming areas for fish cages are found in Bolinao, Anda, Sual, and Dagupan in Pangasinan and Aringay and Sto. Tomas in La Union constituting 114 units covering an approximate area of 8 hectares at the end of 1996. In 2001 however, a recorded 1 170 units were operating in Bolinao and 1 139 units were reported in Dagupan. The continued proliferation of the fish cages in the gulf has been a long standing issue with severe consequences in ecological and socio-economic imbalance. Most common social and environmental impacts are the displacement of artisanal fishers, restriction of navigational routes and deterioration of water quality (BFAR, 2001).

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 (Welcomme, 2001).

Traditional fish traps in the Lingayen Gulf are bamboo stake traps or fish corrals consisting of three parts: leaders, playground and cod-end (Figure 5). Leaders, whose purpose is to guide the fish into the trap, are made of bamboo stakes, netting or branches. Their length varies from 10 to 300 metres, depending on the size of trap. The playground is either a labyrinth, C-shaped or triangular enclosure constructed of bamboo, or wooden stakes driven into the sea-bed, with or without wire netting which has hexagonal meshes. Some larger traps have two playgrounds. The exit from the playground area guides the fish into the cod-end, from where they are scooped. The cod-end is semi-circular, circular or rectangular, with a bamboo or wooden stake frame and covered by polyethylene net and/or wire netting.

The fish corral fisheries ranks fourth after gill nettings, baby trawls and hook and line capture fisheries in Lingayen Gulf with about 7 percent of the total municipal fishers engaged in this type of fishing. This fishery is practiced only along the intertidal zones with vast seagrass beds. The most common target species of fish corrals are the rabbit fishes (*Siganus* spp.) at sizes ranging from 6.8 to 19.4 cm with a modal length of 11.2 cm, this size range is considered too small as this species can potentially reach lengths of 40 cm. Other commercial species which are caught in fish traps and fish corrals are varieties of *Leiognathus, Penaeus* spp., *Scatophagus, Carangoides, Mugil, Rastrilleger* and crustaceans.

FIGURE 5
Fish traps in Lingayen Gulf (Photo: BFAR/N.A.Lopez, 2003)

As of 2001, more than 1 578 units of fish corrals were censused in the general area but numerous fish traps abounds the river inlets and shallow portions of the Gulf such as the fixed or passive types of fishing gears like the fyke nets, fish pots and lever nets at densities which often crowd the passage ways and corridors. These passive types of fishing gears compete with the active types of fisheries for the same fishing grounds. For example, the areas for fish corrals, lever nets and fish traps which are fixed, are the same areas where gill net and hook and line fisheries are also being operated (BFAR, 2001).