Title: USING RADARSAT FOR IMPROVING FISHERIES MANAGEMENT AND FOOD SECURITY IN THE MEKONG RIVER WATERSHED, SOUTH-EAST ASIA

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http://www.hatfieldgroup.com/index.php?sitesig=hg&page=hg_004_RESOURCE_CENTRE&subpage=hg_001_Publications&tm=hg_013_Radar_Overview

Application Tool: Remote Sensing, GIS.

Main Issues Addressed: Habitat Quality and Quantity Linked to Fish Abundance and Distribution.

The general problem, or aim of the study, and the contribution of GIS, remote sensing and/or mapping to the solving the problem: Currently, there is limited understanding of the seasonal hydrological dynamics of the Cambodian floodplain, and its importance for fisheries production. Fisheries habitats in the floodplains of Cambodia play a critical role in food security and livelihoods in the country, however, their importance remain poorly understood by resource managers. Remote sensing data, in particular RADARSAT-1 SAR imagery, serves as an extremely useful tool for providing a synoptic view of the Mekong Basin, and for long-term monitoring of seasonal changes in fisheries resources and aquatic habitats in the region.

Main Environments: Inland.

Culture Systems: Cages.

Organism Divisions: Freshwater fishes.

Genera and Species: Mixed; over 1 200 species in the Mekong Basin.

Target Country: Cambodia.

Target Audience: Fisheries biologists; resource managers; remote sensing specialists.

Duration of the Study and Year Begun: 1.5 years; commenced in 1999.

Personnel Involved:
Thomas Boivin, M.Sc., R.P. Bio. (President, Hatfield Consultants Ltd.). Fisheries biologist and environmental specialist. Team leader and main researcher.
Dirk Werle, M.Sc. (Senior Scientist, AERDE Environmental Research). Geographer/Geophysical Scientist; SAR remote sensing specialist.
Martin Davies, M.E.S., R.P. Bio. (Senior Environmental Specialist, Hatfield Consultants Ltd.). GIS and Remote Sensing data analysis; fisheries habitat assessment.
Malcolm Winsby, M.Sc., R.P. Bio. (Senior Fisheries and Environmental Specialist, Hatfield Consultants Ltd.). Fisheries habitat analysis, field verification of remote sensing data.

USING RADARSAT FOR IMPROVING FISHERIES MANAGEMENT AND FOOD SECURITY IN THE MEKONG RIVER WATERSHED, SOUTH-EAST ASIA

Introduction

The Mekong River is the largest river in Southeast Asia. It supports over 55 millions people within its watershed, which includes areas of China, Myanmar, Thailand, Lao PDR, Cambodia and Viet Nam. The floodplains of the major tributary system, the Great Lake and Tonle Sap River, are critical for fish production in the Mekong basin, and are of particular importance for Cambodia's food security. Natural fish populations in the Mekong Basin are declining as a result of overfishing, habitat destruction, pollution and water-management schemes. A basin-wide approach to fisheries habitat issues, and fisheries management in general, is urgently needed in order to ensure sustainable use of the aquatic resources in the Great Lake and Mekong River Basin.

A critical, poorly understood issue is the extent and duration of seasonal flooding in the Mekong River Basin, particularly in the floodplain of the Great Lake and those of the Tonle Sap and Bassac Rivers in Cambodia. Gaps in the current knowledge base pose a serious obstacle to the conservation and sustainable management of aquatic resources, especially when considered in light of modern technologies and mechanized capacities that make possible over-exploitation of the Great Lake's natural products.

In order to protect and conserve the fisheries resources, it is essential local fisheries managers have access to up-to-date information and cost-effective tools for monitoring fish habitat, fishing activities and potential impact sources. Radar remote sensing is a logical choice in an environment where the most dynamic processes occur in the monsoon season, when cloud coverage is a major obstacle to the effective use of optical remote sensing tools.

The goal of this project was to examine the utility of RADARSAT imagery for fish habitat assessment in the Lower Mekong Basin, particularly in Cambodia. The objective was to develop a system for identifying and monitoring fish habitat, and to assess, from an operational resource management point-of-view, whether RADARSAT is suitable tool to assist local fisheries managers formulate fisheries management and habitat conservation plans for sensitive ecosystems in the Mekong River watershed.

This investigation, which was conducted under the Canadian Radarsat User Development Program (RUDP) funded by the Canadian Space Agency (Montreal, Canada), examined the application of RADARSAT technology for quantification of fish habitat in support of fisheries management. The Mekong River Commission (MRC) in Phnom Penh, Cambodia was the local partner for the project.

Materials and Methods

The methodology employed in this investigation included the following main components:

1. identification of study areas and RADARSAT imagery acquisition planning;
2. search of available background data from MRC and other sources on fisheries and environmental features of the Lower Mekong River Basin and Cambodia;
3. acquisition, analysis and interpretation of RADARSAT-1 and other remote sensing imagery;
4. production of land-use maps derived from aerial photograph interpretation and existing topographic maps;
5. field visits and ground reference data collection to describe and record fisheries habitats, and to verify features identified on the RADARSAT-1 and other imagery; and
6. analysis and interpretation of fisheries habitats in both descriptive and GIS-based formats.

The general area of investigation was the Tonle Sap River and Great Lake region in Cambodia (Figure 1); detailed studies were conducted in the Kampong Chhnang area, which is located in Kampong Chhnang Province, to the north of Phnom Penh. A time series of Wide mode (W2)

RADARSAT-1 imagery was acquired to provide extensive coverage at 30 m resolution of the Great Lake, Tonle Sap River, Bassac River and Mekong River areas. Fine Mode (F3N) RADARSAT-1 imagery was chosen to provide more detailed coverage of the Kampong Chhnang area at 8 m resolution.

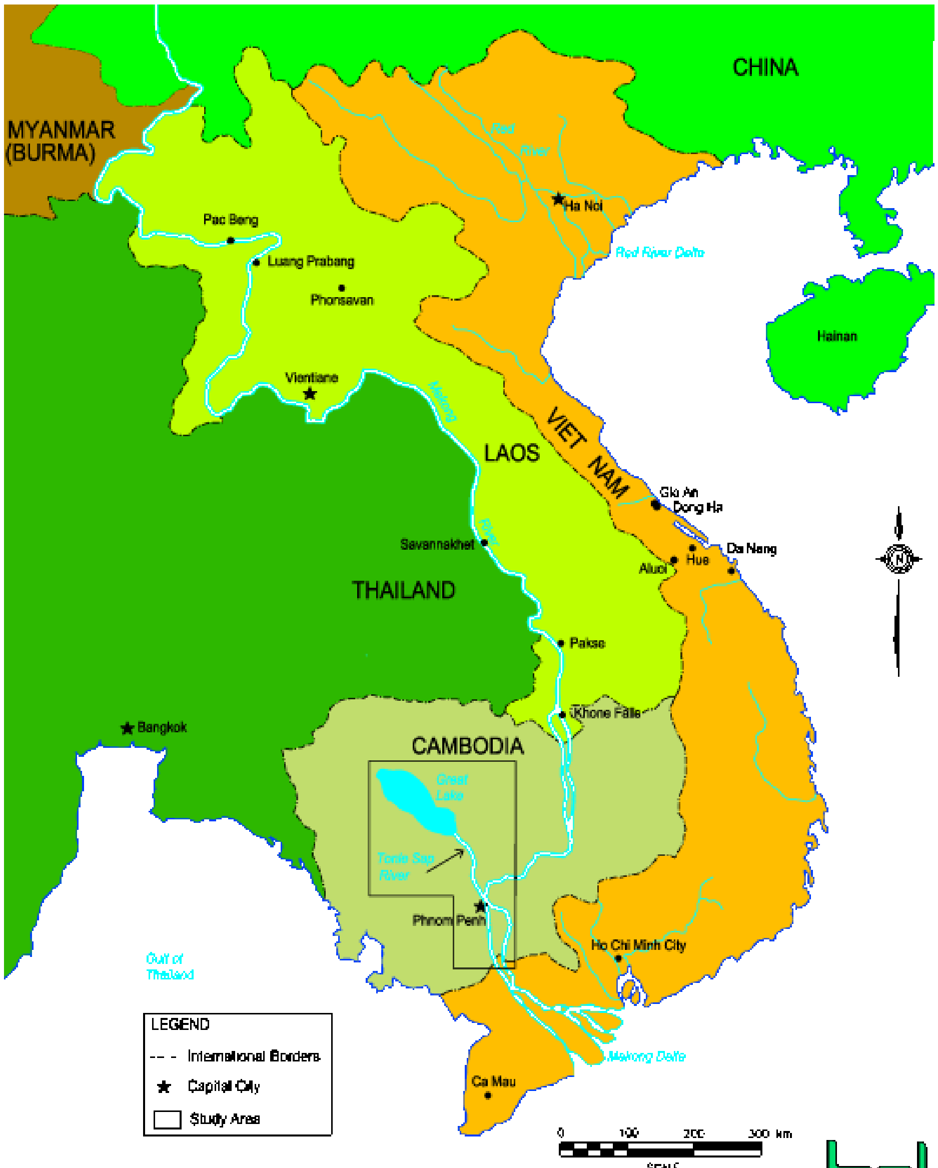

Figure 1 The Mekong River System, showing the study area.

Three visits were made to Cambodia between January 1999 and August 2000 to acquire field data on fisheries and wetland habitats under different seasonal conditions. Habitat assessment methodologies used in this project were based on procedures developed by Cowardin *et al.* (1979), Canadian Department of Fisheries and Oceans (1986) and Kunneke (1997). Field data collection included UTM coordinates of key habitat features; fish capture locations and gear types; fish ponds, and other fixed points (road intersections, buildings, water towers, spirit house locations, pagodas and dams). Aerial photographs, topographic maps, land-use maps and background reports were also used to help identify fisheries habitat features; these were then cross-referenced with the RADARSAT imagery.

Interviews were conducted with subsistence and commercial fishermen (Fishing Lot owners) in Kampong Chhnang Province to obtain data on the operation of the fishery, including key species harvested, number of net checks, average catches, and markets for the catch. Coordinates of barrages, Dai fisheries, and other fishing locations were recorded, and extensive notes were taken to describe the fishery. Data were also collected on rising and receding water levels in the floodplain, and general land use in the study area.

Additional fisheries-related features examined in this investigation included fishing structures (arrow head traps in the Great Lake, barrages, Dai fishing structures, etc.), aquaculture facilities, dykes and dams, and land use (agriculture areas, including flooded rice fields, and infrastructure).

A total of 22 RADARSAT SAR images were acquired during the dry season (May–June 1999), mid-flood season (July–August 1999), peak flood (October 1999) and receding flood period (January–February 2000). Table 1 provides a summary.

Table 1 Summary of RADARSAT SAR Image Acquisitions.

Site / Image	**May/June 1999**	**July/Aug 1999**	**October 1999**	**Jan/Feb 2000**
North of Phnom Penh (Fine)	1	1	1	1
Phnom Penh City Area (Fine)	1	1	1	1
South of Phnom Penh (Fine)	1	1	1	1
Phnom Penh Region (Standard)	1	-	-	-
Tonle Sap / Great Lake (Wide)	3	-	3	3
TOTAL	**7**	**3**	**6**	**6**
GRAND TOTAL = 22				

A multi-temporal RADARSAT SAR data acquisition approach was used in order to capture the environmental dynamics associated with monsoon flooding and its implications for fisheries habitat. Three scenes acquired over the same area at three different times were co-registered, or overlaid, in a red-green-blue colour display. In the resulting composite image, the different colour renditions of the various radar scattering agents on the Earth surface are indicative of physiognomic changes that have affected these surfaces between the different RADARSAT acquisition dates.

PCI EasiPace software was used for digital RADARSAT SAR image processing and extraction of wetland area/fish habitat data. These extracted data, representing areas of open water in each RADARSAT scene processed, were then exported to the project GIS for further processing and analysis.

Spatial information collected during this project was compiled and analysed in an ArcView 3.1 GIS environment including processed RADARSAT imagery, land use data, results of spatial analyses, hot-linked photographs and habitat descriptions, and complete map output layouts from the project (printable in either Tabloid or A3 formats). Intersection (crossing) analysis was undertaken in ArcView using RADARSAT-derived flooding categories (i.e. open water/upland/not classified) and Cambodia land-use and cover classification system (CLUCCS; Kunneke, 1997) land cover data. These intersection analyses provided estimates of the amount of each CLUCCS land cover type that was flooded (i.e. open water), upland, or not classified, in each study area at each time of RADARSAT image acquisition.

Results

The RADARSAT data sets collected before, during and after the 1999–2000 flooding season (May 1999 – January 2000) provide new spatial insights into the dynamics of the flood regime in the Great Lake and Tonle Sap River basin. From the analysis of the flood regime, we assessed the extent of fish habitat and its seasonal spatial variations using Wide and Fine mode RADARSAT imagery.

The RADARSAT-1 Wide mode (W2) mosaics produced in this study successfully portrayed the regional hydrological situation and land use shortly before the onset of monsoon (May), at the peak of the monsoon season (October), and after the monsoon season (January) (Figure 2).

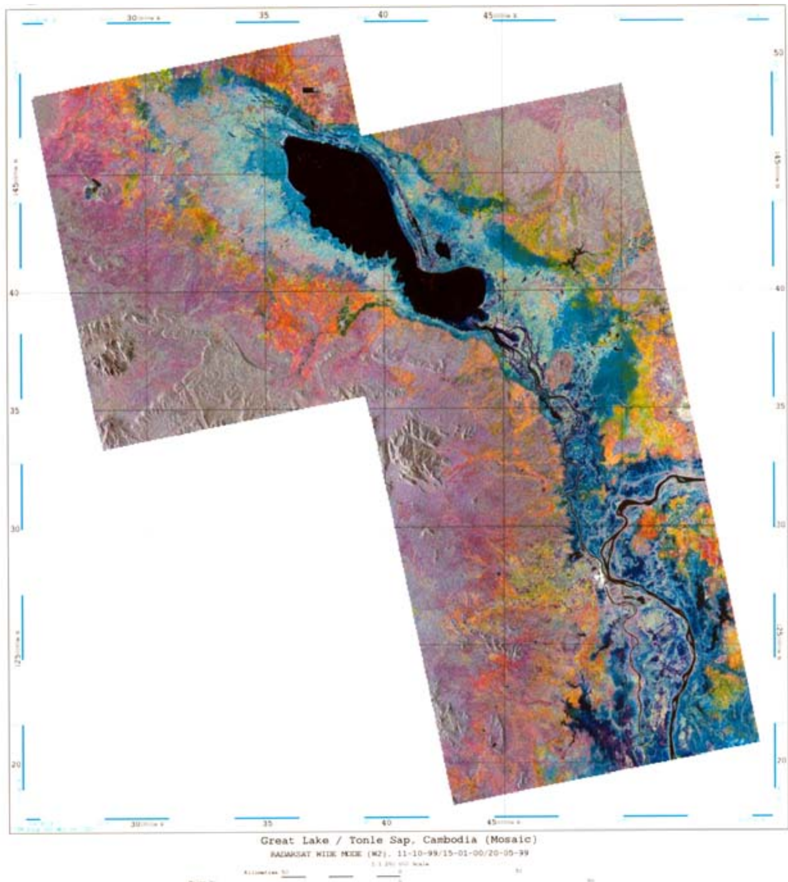

Figure 2 Multi-temporal Wide Mode (W2) 3-date RADARSAT composite image, Great Lake and Tonle Sap River, Cambodia (May 1999, October 1999 and January 2000).

Flooded habitats were quantified for the Great Lake and Tonle Sap watershed though extraction of open water areas from mosaicked Wide Mode RADARSAT imagery collected in May/June 1999, October 1999, and January/February 2000; the overall extent of these open water areas was quantified in the Project GIS (Table 2).

Table 2 Flooded areas of the Great Lake, corresponding to areas of open water in each RADARSAT scene (May 1999–February 2000).

Date of RADARSAT Image Acquisition	**Total Extent of Open Water (ha)**	**Difference from Low Water Condition (ha)**
May/June 1999 (early flooding season)	351 653	(0)
October 1999 (peak of flooding)	1 282 603	930 950
January/February 2000 (receding flood)	475 977	124 324

The RADARSAT-derived flooding data confirm that at least 1 000 000 hectares (10 000 km^2) of land area is flooded seasonally in the Great Lake/Tonle Sap watershed, representing approximately a four-fold increase in inundated area over the year, with a corresponding increase in available fisheries habitat. In years of intense flooding, the floodplain area may expand up to six times its dry-season size; hence, there is a need for data collection over a time series (i.e. 3-year flooding cycle) to determine inter-year variation and confirm the maximum extent of the Great Lake/Tonle Sap floodplain.

Attempts were made to identify arrow-shaped traps and other large fishing structures in the Great Lake. A multitude of radar signatures related to fishing structures can be readily observed in the individual (May and January) and multi-temporal Wide mode imagery of the Great Lake (Figure 3).

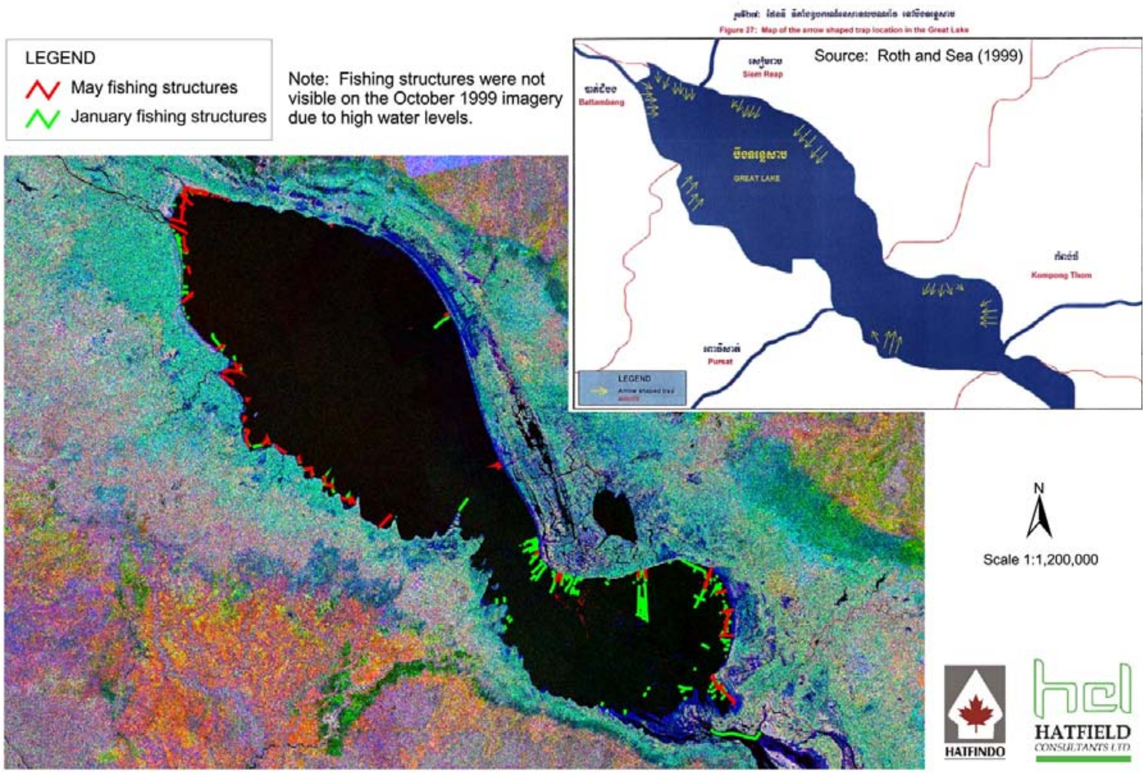

Figure 3 Location of fishing structures on the Great Lake, Cambodia, derived from multi-temporal Wide Mode composite imagery (May 1999–January 2000).

Strong radar returns were observed from arrowhead traps, which consist of a series of wooden poles and weirs on the shoreline of the lake. The location of these fishing structures on the Great Lake as seen in the RADARSAT imagery is similar to that presented by Roth and Sea (1999; see inset of Figure 3). However, additional gears are identified in the south-west corner of the Great Lake which are not reported by Roth and Sea (1999); conversely, some fishing structures which are known to be located in the north-west corner of the Great Lake were not seen in the imagery.

Individual Fine Mode RADARSAT scenes and multi-temporal imagery were used to identify and delineate different fisheries habitats in the Kampong Chhnang area (including Fishing Lot 14), in the Tonle Sap River main stem (Figures 4 and 5).

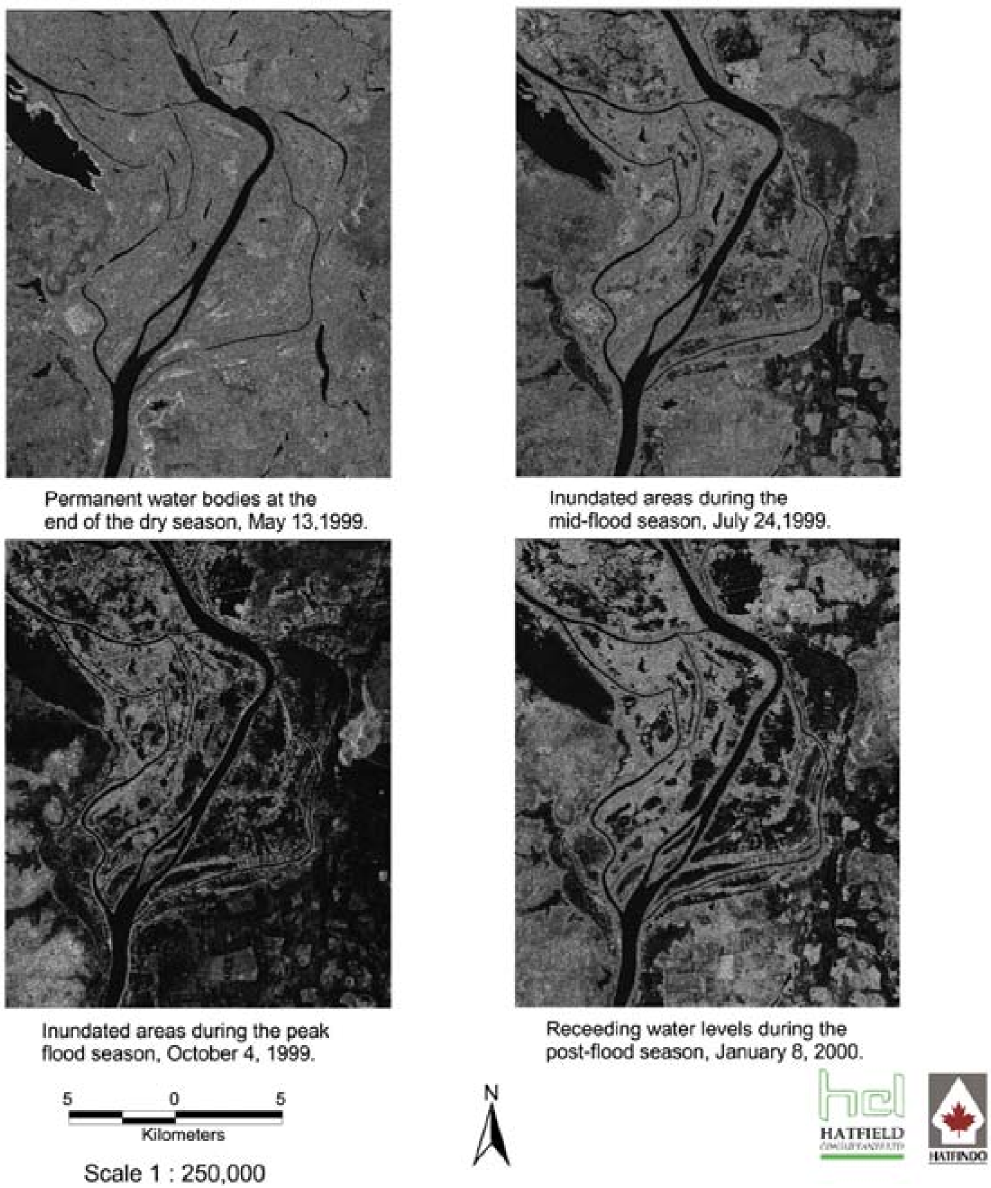

Figure 4 Progression of flooding in May, July and October 1999 and January 2000 in the Kampong Chhnang area of Cambodia, as seen in RADARSAT-1 Fine Mode SAR Imagery.

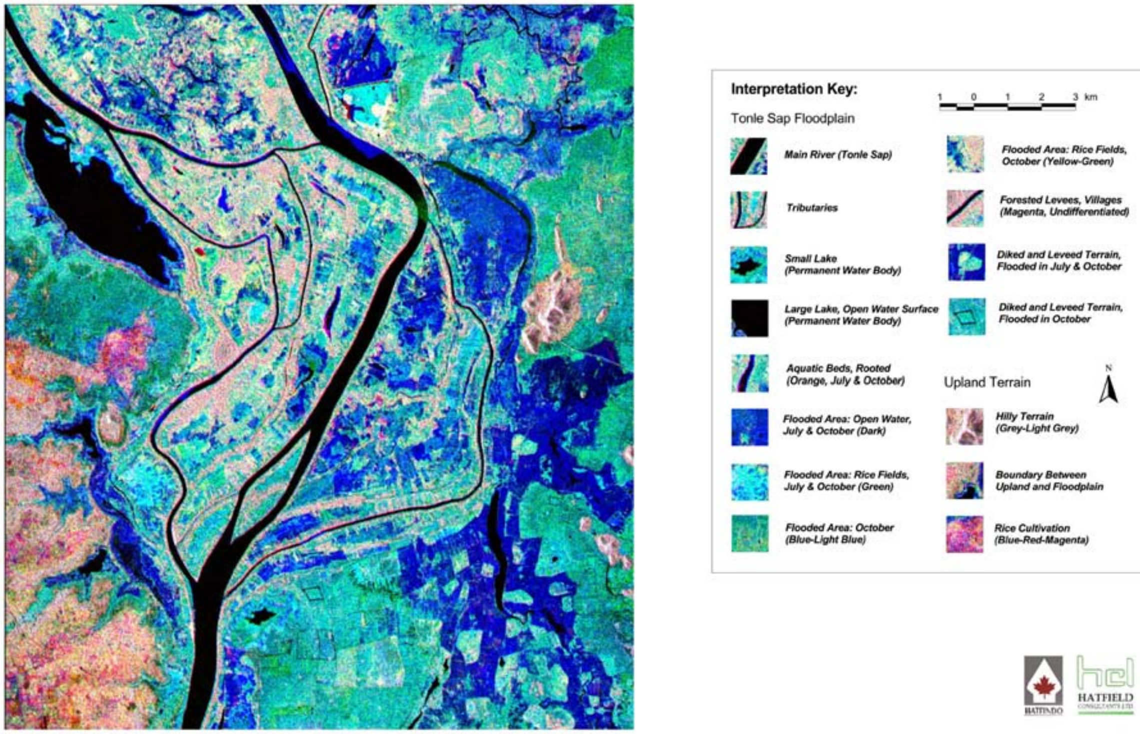

Figure 5 Fisheries habitat assessment in Study Area 2 using RADARSAT Fine Mode 3-date composite imagery (Blue: May 1999, Green: July 1999 and Red: October 1999).

Fisheries habitat features which can be identified in the four-date composite image include: permanent and seasonal water bodies, rivers, tributaries, flooded terrain, water management schemes, rice cultivation, floating and emergent vegetation, and villages. These habitat features were verified in the field following consultation with local villagers.

Results of GIS intersection analyses include estimates of flooding of various land cover classes, and calculations of available fish habitat in wetlands, agricultural areas, the mainstream river and lake habitats. The total area for which fisheries habitat analyses were undertaken covered 23 996 ha (240 km^2), extending approximately 16.0 km from north to south and 15.0 km from east to west. In this reach of the Tonle Sap River, the floodplain is wide; upland areas occur only along the western border of the river.

Quantitative estimates of the extent of flooding (open water) during the 1999–2000 flooding season, derived from RADARSAT imagery and GIS analysis (Figure 6 and Table 3), illustrate the significant change in inundated fisheries habitats at different periods of the Tonle Sap flood cycle.

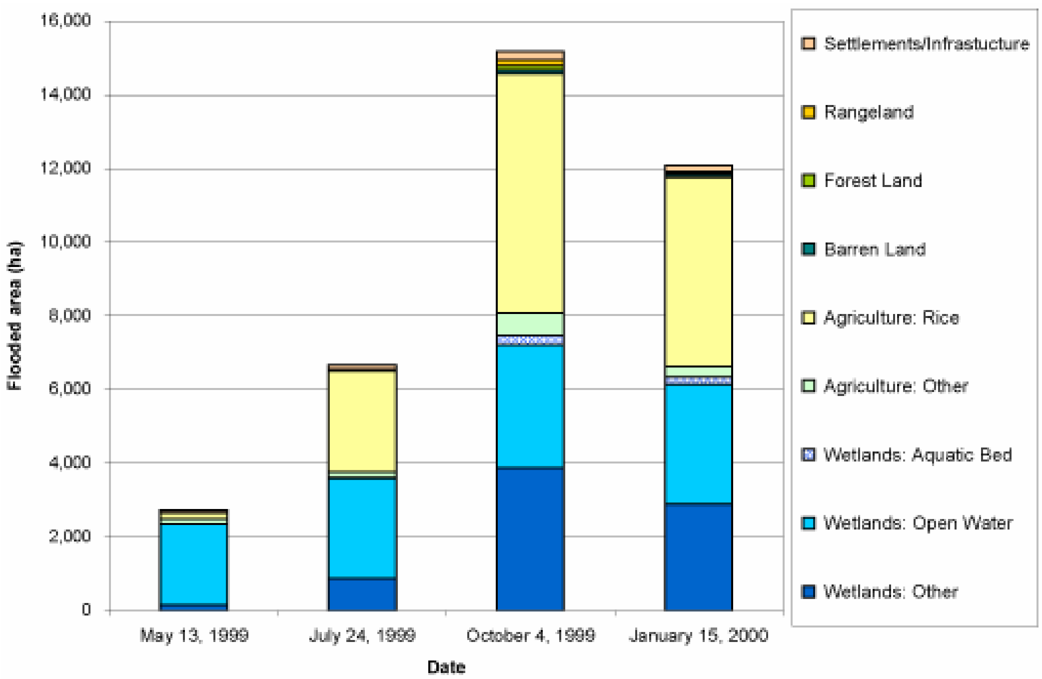

Figure 6 Extent of flooded habitats, classified by land-use type, Kampong Chhnang, Cambodia, May 1999 to January 2000.

Table 3 Extent of flooded habitats, classified by land-use type, Kampong Chhnang, Cambodia, May 1999 to January 2000.

Land Use Category (Modified CLUCCS Classification)	**Total Study Area** (ha)		**Area Flooded** (ha)							
	Floodplain + Upland	Floodplain Only	**May 13, 1999**		**July 24, 1999**		**October 4, 1999**		**January 15, 2000**	
			Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Agriculture: Rice	8193.1	7524.7	184.1	2.4%	2742.2	36.4%	6496.8	86.3%	5136.9	68.3%
Agriculture: Other	1063.8	1063.8	123.2	11.6%	151.1	14.2%	616.5	58.0%	292.4	27.5%
Barren land	245.4	210.1	1.8	0.8%	8.1	3.9%	104.0	49.5%	62.8	29.9%
Forest Land	311.4	268.8	3.1	1.2%	16	6.0%	113.7	42.3%	53.3	19.8%
Rangeland	403.7	205.3	3.8	1.9%	11.8	5.8%	162.6	79.2%	38.6	18.8%
Settlements/ Infrastructure	715.8	612.6	62.2	10.1%	130.3	21.3%	227.1	37.1%	158.6	25.9%
Wetlands: Open Water	3945.6	3943.1	2203.4	55.9%	2719.5	69.0%	3336.0	84.6%	3248.2	82.4%
Wetlands: Aquatic Bed	415.8	413.7	10.7	2.6%	29.8	7.2%	245.8	59.4%	202.2	48.9%
Wetlands: Other	8700.2	8654.3	132.0	1.5%	860.4	9.9%	3878.0	44.8%	2886.1	33.3%
Total Area Flooded (ha)	**23994.8**	**22896.4**	**2724.3**	**11.9%**	**6669.2**	**29.1%**	**15180.5**	**66.3%**	**12079.1**	**52.8%**

The ability of RADARSAT data to identify and quantify the extent of inundation, and to assess seasonal and annual variation in flooding in key habitats, verifies its utility for supporting fisheries management in the Lower Mekong Basin. A preliminary identification of advantages and disadvantages of RADARSAT imagery for fisheries habitat assessments and environmental assessment is presented in Table 4.

Table 4 Advantages and disadvantages of using RADARSAT data for fisheries habitat assessment and environmental monitoring in the Lower Mekong Basin.

Criteria	**Advantages**	**Disadvantages**
Timing	Data can be acquired at any time/season, given the satellite's ability to penetrate cloud cover. One can reliably schedule imagery acquisitions at any time (i.e. it allows robust *a priori* study design for time-series data, which is difficult with other remote sensing data).	Imagery acquisition planning requires knowledge of the RADARSAT beam modes, incidence angles and other properties of the satellite to be most effective. Acquisition timing must be coordinated with requests for images by other users when multiple requests are received for the same time periods.
Coverage	Both a synoptic and detailed view of the habitats can be obtained. Different satellite beam modes and incidence angles allows for high or low-resolution imagery to be collected, as needed.	Undoubtedly, area of coverage for a target area will be at times greater than the area covered by a single image or swath during a single orbit.
Application/Use	Multi-temporal imagery can provide essential change detection data for monitoring purposes over large geographical areas. Proven to be effective for variety of aquatic environmental applications, including flooding, coastal zone monitoring, land use changes, etc. RADARSAT data are most effective when used in conjunction with other data sources.	Technology transfer requirements, including training of remote sensing personnel in image analysis and interpretation. Interpretation is 'different' from optical imagery, so new users must accustom themselves to new methods of data interpretation. The short duration of the current study did not permit detailed refinement of flooded/exposed vegetation (forest canopy) on shoreline areas of the Great Lake.
Comparison with other methods	More cost-effective than aerial surveys and other methods when planned efficiently. Complimentary to other remote sensing data sources.	Lower resolution compared to large-scale aerial photos.

Discussion

Unique Aspects of the Study

This project was the first application of remote sensing, and particularly RADARSAT data, for fisheries habitat assessment and environmental monitoring in the Lower Mekong Basin. Prior to conducting this study, there were serious gaps in knowledge of essential hydrological features of the Great Lake and Tonle Sap system, including timing, extent, and duration of seasonal flooding, and its impact on availability of fisheries habitat.

Lessons learned

Given more or less continuous cloud cover conditions during the period of image acquisition (from May, 1999 to January, 2000), RADARSAT data were used effectively for delineating permanent water bodies (rivers, tributaries, lakes, refugia); seasonal water bodies; extent of inundation at different flooding levels; land use (rice agriculture areas, aquaculture developments); fishing structures; and fishing activities (barrages, arrowhead traps, Dai fishing activities).

Problems Encountered

Although vegetation classes such as floating and emergent vegetation were also identified using the remote sensing data, flooded forest habitats were more difficult to interpret. RADARSAT data were less effective at delineating extent of flooding under thick vegetation canopy. Consideration of additional RADARSAT acquisition dates may help to better discern flooded from non-flooded vegetation. A combination of RADARSAT data with other remote sensing data may also provide better discrimination of these features.

Field Verification

RADARSAT imagery were field-tested at different periods in the flood cycle (dry season, rising flood, peak flood and post-flood) during this project. Field studies verified the following, which were also recorded on the remote sensing imagery:

- extent and duration of seasonal flooding in the Great Lake/Tonle Sap Basin;
- permanent water bodies (rivers, tributaries, lakes, dry season refugia);
- seasonal water bodies (floodplain habitats);
- floodplain margins, upland runoff and patterns of inundation in main waterbodies;
- land use (rice agriculture areas, aquaculture developments);
- fishing structures and fishing activities (barrages, arrowhead traps, Dai fishing activities);
- aquaculture ponds;
- local dykes and dams;
- areas of flooded fixed vegetation, including patches of flooded rice paddies; and
- floating or rooted beds of aquatic vegetation.

Future Directions

The results of this study indicate that RADARSAT has good potential for application to fisheries and aquatic resource assessment in floodplain areas. Results have shown that this technology can be applied to distinguish fisheries habitat, fishing gears, and other environmental features, over broad geographical areas at different periods in the annual flooding cycle. RADARSAT information is best displayed using multi-temporal composite imagery, which permits change detection analysis over a period of time.

The ability of RADARSAT imagery to see through clouds and inclement weather conditions is one of the main features that makes it ideally suited for monitoring of floodplains, wetlands and fisheries habitats in Southeast Asia. When displayed in a GIS format with other remote sensing, fisheries and environmental data, RADARSAT information can be used to quantify the extent of flooding in different fisheries habitats, and therefore assist fisheries managers to identify key areas for conservation and protection.

There is strong potential for on-going use of RADARSAT imagery for fisheries applications in Southeast Asia and other parts of the world, particularly when used in conjunction with other remote sensing tools (such as aerial photos), field surveys and background environmental information.

From a regional perspective, information on extent and duration of flooding is needed by a variety of user groups in the Lower Mekong Basin. These include fisheries managers, water management specialists, environmental managers, agriculture specialists and other local agencies responsible for environmental monitoring. Integration of remote sensing imagery, fisheries information and other environmental and socio-economic data in a GIS format is an effective method for displaying, analysing and disseminating vital information to all user groups.

A basin-wide approach to fisheries management, fish habitat conservation, and environmental monitoring is urgently needed in order to protect natural resources utilized by over 55 millions people living in the Mekong Basin. Protection of aquatic habitats will result in protection of fisheries resources, which, in turn, will help ensure long-term food security in the Mekong Basin.

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