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MONITORING OF LARGE WATERBIRDS AT PREK TOAL, TONLE SAP GREAT LAKE 2001 – 2007

GEF

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Acronyms

FiA	Fisheries Administration (formerly Department of Fisheries)
GIS	Geographical Information System
GPS	Global Positioning System
MAF	Mission Aviation Fellowship
MAFF	Ministry of Agriculture, Forestry and Fisheries
MoE	Ministry of Environment
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
TSBR	Tonle Sap Biosphere Reserve
TSCP	Tonle Sap Conservation Project
TSEMP	Tonle Sap Environmental Management Project
UTM	Universal Transverse Mercator
WCS	Wildlife Conservation Society
WUP-FIN	Modelling of the Flow Regime and Water Quality of the Tonle Sap

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The authors would like to acknowledge the contribution of those WCS Cambodia staff who helped with the immense task of processing six years of monitoring data from Prek Toal. They are: Meak Khun and Chan Vibol (GIS processing of aerial images and map production), Sorn Pheakday (database management) and the data entry team Ngin Kam San, Bun Soir and Vong Pheakday. Due to the enormous volumes of data involved in this project, this report could not have been produced without their invaluable assistance. We would also like to thank Emil Kundig, of the Mission Aviation Fellowship (MAF) Cambodia, who admirably coped with the challenge of flying aerial surveys over Prek Toal, and Don Cooney, who conducted several ultralight surveys.

This report builds on a monitoring system first introduced to Prek Toal by Frederic Goes, without whose work the current report would be impossible. Both Pete Davidson and Robert Timmins provided valuable insights into species ecology and distribution in the region. Matti Kummu kindly shared his own research into the potential impact of development projects on the Tonle Sap Great Lake. Finally, the analysis would have been impossible without Samantha Strindberg's statistical advice.

Executive Summary

The Tonle Sap Great Lake large waterbird colonies, discovered in the mid-1990s at Prek Toal, are of global conservation importance. The colonies include the largest, and in some cases the only, breeding populations in South-east Asia of seven species of conservation significance: Spot-billed Pelican *Pelecanus philippensis*, Milky Stork *Mycteria cinerea*, Painted Stork *Mycteria leucocephala*, Lesser Adjutant *Leptoptilus javanicus*, Greater Adjutant *Leptoptilus dubius*, Black-headed Ibis *Threskiornis melanocephalus* and Oriental Darter *Anhinga melanogaster*. The birds are reliant on the unique Tonle Sap ecosystem, the largest freshwater lake in South-east Asia and one of the world's most productive fisheries.

When first discovered the colonies were heavily threatened by annual harvesting of the eggs and chicks by nearby villagers, mainly for trade and local consumption. This led to the establishment in early 2001 of the Prek Toal conservation team. Beginning with the initial four and expanding to the current 28 rangers, this team has conducted annual monitoring and protection of the breeding bird colonies since 2001. The team has been remarkably effective: collection incidences declined in 2002 and 2003, and since 2004 all species have bred successfully. The rangers' skills at bird identification and counting led to the development of a simple counting system, based on weekly observations of all nesting birds visible from the observation platforms.

By 2003 it became clear that the colonies were being effectively protected and possible increases in the population of one species, the Oriental Darter, were observed. In order to measure these population changes more accurately a monitoring program was developed and implemented over four years, from 2004-2007. The monitoring program aimed to provide scientifically robust estimates of the bird populations each year, both to measure individual trends and to provide accurate information on the total number of birds present. If the annual egg and chick collection was the major threat to the target species, then increases would be expected at a rate consistent with the species' ecology. Conversely, constant or declining populations would be indicative of unknown threats elsewhere in the species' range. Under the program design, the platform count data recorded by the rangers is taken as a random representative sample of the species present and their densities. These are then extrapolated across the entire area known to be occupied by each species, based on detailed tree mapping by boat surveys during the wet season and aerial surveys at the peak colony breeding time. High-resolution overlapping digital photographs taken during these aerial surveys allow accurate determination of the total colony extent and the number of trees occupied.

The monitoring program has fulfilled its original objectives and has provided robust scientific estimates of the populations of three species (Spot-billed Pelican, Painted Stork and Asian Openbill) since 2004, and for Oriental Darter since 2001. In addition, partial population estimates for three further species (Greater and Lesser Adjutant and Milky Stork) have been possible, based on the platform counts. Estimates are based on the number of breeding pairs, and 95% confidence intervals are shown in brackets. Approximate baseline populations for the all species in 2001 are given. Population estimates for Black-headed Ibis were not possible to calculate.

Species	Number of breeding pairs (Confidence Interval)			Notes
	2001	2004	2007	
Asian Openbill	600 (approx.)	959 (611-1,307)	7,682 (6,286-9,078)	Complete estimate
Greater Adjutant	30 (approx.)	56 (49-63)	77 (65-89)	Partial Estimate
Lesser Adjutant	40 (approx.)	158 (127-189)	253 (222-284)	Partial Estimate
Milky Stork	unknown	2	10 (6-14)	Partial Estimate
Black-headed Ibis	200 (approx.)		1,000 (approx.)	
Oriental Darter	241 (118-364)	1,125 (819-1,431)	4,053 (3,463-4,643)	Complete Estimate
Painted Stork	1,000 (approx.)	1,707 (1,523-1,890)	3,121 (2,854-3,388)	Complete Estimate
Spot-billed Pelican	700 (approx.)	1,117 (977-1,258)	2,592 (2,301-2,883)	Complete Estimate

The results indicate that the Prek Toal conservation program has been extremely effective. All species have recorded significant increases, with populations in some cases as much as 20 times greater than when the program was initiated. Some species, such as Oriental Darter and Painted Stork, are now colonising new nesting sites in Cambodia and Thailand. Similar range expansions might be expected for other species (e.g. Spot-billed Pelican) in future years. The colonies do not appear to be currently limited at Prek Toal, either for food or for nesting locations, although this may change as the populations continue to increase. The success of the Prek Toal program has contributed to recent proposals for revisions of species status, such as down-listing of Spot-billed Pelican based on the observed population recoveries.

The Prek Toal monitoring program is time-consuming and requires significant technical resources. Future monitoring may use a number of indicators, which can be expected to correlate with changes in total population size, and will be simpler to collect. Further research is required to investigate breeding ecology and to monitor species migrations to feeding sites. Little is currently known about how species disperse from Prek Toal and how populations interchange with those breeding at other sites (such as nesting Adjutant storks in northern Cambodia). Over the next twenty years significant changes in the hydrological and ecosystem processes of the Tonle Sap are expected as a consequence of development initiatives upstream in the Mekong River. Recent modelling suggests that these may substantially alter water levels and sedimentation rates, which may see a decline in the distribution and abundance of the emergent trees that the birds use as nesting habitat. Monitoring the impact of these changes on the birds' habitat will be a significant challenge in future years.

សេចក្តីសង្ខេប

បឹងទន្លេសាបគឺជាទីជម្រករស់នៅដ៏ធំនៃពពួកសត្វស្លាបទឹកដែលនៅក្នុងនោះមានតំបន់ព្រៃកទាល់ត្រូវបានរកឃើញនៅពាក់កណ្តាលទសវត្សនៃឆ្នាំ ១៩៩0 និងជាតំបន់មានសារសំខាន់ជាសាកលចំពោះការអភិរក្សសត្វស្លាបទឹកគ្រប់ប្រភេទ។ ទីជម្រករស់នៅនេះ មិនគ្រាន់តែមានទំហំធំធេងប៉ុណ្ណោះទេ ថែមទាំងជាទីកន្លែងបង្កាត់ពូជ ឬពងកូនដ៏ធំជាងគេនៅតំបន់អាស៊ីអគ្នេយ៏ ជាពិសេសសម្រាប់ការអនុវត្តគម្រោងអភិ-រក្សប្រភេទសត្វស្លាបសំខាន់ៗទាំង៧ប្រភេទ រួមមាន ទុងប្រផេះ (*Pelecanus philippensis*) រនាលស (*Mycteria cinerea*) រនាលពិណ (*Mycteira leucocephala*) ត្រដក់តូច (*Leptoptilus javanicus*) ត្រដក់ធំ (*Leptoptilus dubius*) ត្រយ៉ងខ្លួនស (*Threskiornis melanocephalus*) និងស្មោញ (*Anhinga melanogaster*)។ ពួកសត្វស្លាបទឹកទាំងនេះរស់នៅពឹងអាស្រ័យលើស្ថានិកប្រព័ន្ធអេកូឡូស៊ីទន្លេសាប ដែលជាបឹងទឹកសាបធំជាងបឹងដទៃទៀតនៅក្នុងតំបន់អាស៊ីអគ្នេយ៏ និងជាបឹងដែលស្តុកត្រីទឹកសាបច្រើនជាងគេនៅលើពិភពលោក។

នៅពេលរកឃើញដំបូង ទីជម្រកនេះរងការគំរាមកំហែងយ៉ាងធ្ងន់ធ្ងរពីការប្រមូលយកពង និងកូនដោយអ្នកភូមិដែលរស់នៅក្បែរតំបន់នេះ ដើម្បីធ្វើការលក់ដូរ និងផ្គត់ផ្គង់ការប្រើប្រាស់នៅក្នុងស្រុក ឬក្នុងតំបន់ដែលអ្នកភូមិរស់នៅក្បែរតំបន់នោះ។ កត្តានេះបានធ្វើឱ្យមានការបង្កើតក្រុមអភិរក្សតំបន់ព្រៃកទាល់នេះជាលើកដំបូងនៅក្នុងឆ្នាំ ២00១។ នៅពេលចាប់ផ្តើមក្រុមនេះមានមន្ត្រីអនុរក្សចំនួន ៤នាក់ ហើយដែលបច្ចុប្បន្នបានកើនឡើងដល់២៨នាក់។ ក្រុមនេះចុះតាមដាន ត្រួតពិនិត្យ និងការពារទីជម្រករស់នៅ និងពងកូនពពួកសត្វស្លាបទឹកទាំងនោះជាប់ជាប្រចាំ តាំងពីឆ្នាំ ២00១ មកម្ល៉េះ។ ក្រុមនេះបានទទួលលទ្ធផលគួរឱ្យកត់សម្គាល់ រួមមាន: នៅឆ្នាំ ២00២ និង ២00៣ ក្រុមនេះប្រមូលបានព័ត៌មានពាក់ព័ន្ធនឹងភាពបង្គ្រោះថ្នាក់ទាំងសត្វស្លាប និងទីជម្រករស់នៅ និងចាប់តាំងពីឆ្នាំ ២00៤ គ្រប់ប្រភេទសត្វទាំងអស់បានបន្តពូជដោយជោគជ័យ។ ចំណេះដឹងរបស់មន្ត្រីលើការវិនិច្ឆ័យអត្តសញ្ញាណបក្សី និងការរាប់ចំនួនសត្វ បានឈានទៅរកភាពងាយស្រួលលើការរាប់ ដោយបានចុះអង្កេត និងរាប់សំបុកពងសត្វស្លាបទាំងអស់ រៀងរាល់សប្តាហ៏។

នៅឆ្នាំ ២00៣ តំបន់ព្រៃកទាល់នេះ បានក្លាយជាតំបន់ការពារដីមានប្រសិទ្ធិភាព និងសារព័ន្ធប្រភេទស្មោញ (Population of Darter) មានការកើនឡើងច្រើន។ ដើម្បីវាយតម្លៃការប្រែប្រួលសារព័ន្ធប្រភេទទាំងនេះ កម្មវិធីត្រួតពិនិត្យតាមដានដែលមានរយៈពេល ៤ឆ្នាំ (ពីឆ្នាំ ២00៤-២00៧) មួយត្រូវបាន

បង្កើតឡើង។ កម្មវិធីនេះមានគោលបំណងផ្តល់ការយល់ដឹងលើការវាយតម្លៃតាមមូលដ្ឋានវិទ្យាសាស្ត្រ នូវសារព័ន្ធប្រភេទសត្វស្លាបទឹកទាំងអស់រៀងរាល់ឆ្នាំ ការវាយតម្លៃភាពធ្លាក់ចុះឬកើនឡើង និងផ្តល់ព័ត៌មានអំពីចំនួនសរុបនៃសត្វស្លាបទឹកដែលមានវត្តមាននៅក្នុងតំបន់។ ប្រសិនបើការប្រមូលពង កូនរាល់ឆ្នាំក្លាយទៅជាបញ្ហាគំរាមដល់ប្រភេទសំខាន់ៗខាងលើនេះមែន នោះកំណើនអាចគិតតាមអត្រាមួយដែលមានលក្ខណៈស្របទៅនឹងមជ្ឈដ្ឋានរបស់ប្រភេទទាំងនោះ។ ផ្ទុយទៅវិញ ភាពមិនប្រែប្រួល ឬការថយចុះសារព័ន្ធប្រភេទអាចបង្ហាញពីកត្តាគំរាមកំហែងផ្សេងទៀត ដែលយើងមិនបានដឹងនៅក្នុងដែនដែលមានប្រភេទសត្វស្លាបទាំងនោះរស់នៅ។ក្នុងកម្មវិធីនេះ រានសម្រាប់រាប់ កត់ត្រាវត្តមានសត្វស្លាប និងដង់ស៊ីតេរបស់វាត្រូវបានដំឡើងសម្រាប់មន្ត្រីអភិរក្សបំពេញការងារ។ រានទាំងនេះ អាចជួយឱ្យមន្ត្រីអភិរក្សសិក្សាប្រៀបធៀប និងដឹងអំពីវត្តមានលំអិតនៃប្រភេទនីមួយៗដែលមាននៅក្នុងតំបន់នេះ តាមរយៈការឆ្លុះមើលសត្វដែលទុំលើមែក ឬដើមឈើ ការចុះអង្កេតតាមទូកនាវដូវទឹកឡើង និងការចុះអង្កេតតាមយន្តហោះក្នុងតំបន់ដែលមានសត្វពងនៅរដូវបន្តពូជ។ រូបភាពច្បាស់ៗ តាមម៉ាស៊ីនថតស្វ័យប្រវត្តិពីលើយន្តហោះ បានបង្ហាញឱ្យឃើញពីការកើនឡើងទាំងចំនួនសត្វស្លាប និងទាំងចំនួនដើមឈើដែលសត្វទុំ។

កម្មវិធីតាមដានត្រួតពិនិត្យត្រូវបានអនុវត្តតាមផែនការ និងបានធ្វើការប៉ាន់ស្មានសារព័ន្ធប្រភេទចំនួនបី: គឺទុងប្រផេះ រនាលពិណ និង ចង្កៀលខ្យង នៅឆ្នាំ ២០០៤ និងពពួកស្មៅញាតាំងពីឆ្នាំ ២០០១ មកម្ល៉េះ។ លើសពីនេះទៅទៀត ការប៉ាន់ស្មានសារព័ន្ធប្រភេទពីលើរានសម្រាប់រាប់ កត់ត្រា ត្រូវបានអនុវត្តទៅលើប្រភេទបីបន្ថែមទៀត គឺ ត្រដក់តូច ត្រដក់ធំ និងរនាលស។ វិធីសាស្ត្រប៉ាន់ស្មាន គឺផ្អែកទៅលើចំនួនគូដែលអាចបង្កាត់ពូជបាន។

ប្រភេទ	ចំនួនគូបង្កាត់ពូជ ចំនួនប៉ាន់ស្មាន ឆ្នាំ១	ចំនួនគូបង្កាត់ពូជ ចំនួនប៉ាន់ស្មានឆ្នាំ២	សម្គាល់
ចង្កៀលខ្យង	959 (611-1,307)	7,682 (6,286-9,078)	ប៉ាន់ស្មានរួច
ត្រដក់ធំ	56 (49-63)	77 (65-89)	ប៉ាន់ស្មានមានលំអៀង
ត្រដក់តូច	158 (127-182)	253 (222-284)	ប៉ាន់ស្មានមានលំអៀង
រនាលស	2	10 (6-14)	ប៉ាន់ស្មានមានលំអៀង
ស្មៅញ	241 (118-364)	4,053 (3,463-4,643)	ប៉ាន់ស្មានរួច
រនាលពិណ	1,707 (1,523-1,890)	3,121 (2,854-3,388)	ប៉ាន់ស្មានរួច
ទុងប្រផេះ	1,117 (977-1,258)	2,592 (2,301-2,883)	ប៉ាន់ស្មានរួច

ទី១ : ប៉ាន់ស្មានក្នុងឆ្នាំ ២០០៤ លើកលែងតែសត្វស្មោញដែលធ្វើនៅក្នុងឆ្នាំ ២០០១
ទី២ : ប៉ាន់ស្មានក្នុងឆ្នាំ ២០០៧

លទ្ធផលខាងលើនេះបង្ហាញថា កម្មវិធីអភិរក្សតំបន់ព្រៃកទាល់បានទទួលជោគជ័យច្រើន និងមានប្រសិទ្ធិ-ភាព។ គ្រប់ប្រភេទទាំងអស់មានការកើនឡើងច្រើន គឺសារព័ន្ធប្រភេទខ្លះមានការកើនឡើង២០ដង បើប្រៀបធៀបទៅនឹងការចាប់ផ្តើមដំបូងនៃកម្មវិធី។ ប្រភេទខ្លះ ដូចជាស្មោញ និងរនាលពិណ ត្រូវបានកត់ត្រាថ្មីថា មានរស់នៅ និងពងកូននៅក្នុងប្រទេសកម្ពុជា និងថៃ។ ការប៉ាន់ស្មានចំពោះប្រភេទខ្លះដែលមានស្ថានភាពស្រដៀងគ្នានេះដូចជា ទុងប្រផេះ ក៏នឹងត្រូវធ្វើឡើងក្នុងឆ្នាំខាងមុខនេះផងដែរ។ ទីជម្រករស់នៅរបស់សត្វស្លាបនៅតំបន់ព្រៃកទាល់ទាំងនេះមិនមែនគ្រាន់តែជាទីកន្លែងសម្រាប់រកចំណី និងពងកូនប៉ុណ្ណោះទេ គឺវាអាចកំណត់អំពីភាពបំរែបំរួលសារព័ន្ធនៃប្រភេទសត្វស្លាបផងដែរ ដូចជាកំណើនសារព័ន្ធប្រភេទដែលកំពុងបន្តកើនឡើងថែមទៀតផង។ ភាពជោគជ័យនៃការអនុវត្តកម្មវិធីអភិរក្សតំបន់ព្រៃកទាល់នេះ បានចូលរួមចំណែកដល់ការលើកគម្រោងនានាដែលជាប់ពាក់ព័ន្ធនឹងការសិក្សាវាយតម្លៃអំពីស្ថានភាពរស់នៅនៃពពួកសត្វស្លាបសំខាន់ៗដូចជា: ការដកប្រភេទទុងប្រផេះចេញពីក្រុមប្រភេទជិតផុត ពូជជាដើម ព្រោះដោយសារតែការរកឃើញថាសារព័ន្ធប្រភេទនេះមានការកើនឡើង។

កម្មវិធីតាមដានត្រួតពិនិត្យមានការគិតគូរអំពីពេលវេលា និងតម្រូវការធនធានបច្ចេកទេសសំខាន់ៗមួយចំនួន។ នាពេលអនាគត ការតាមដានអាចប្រើប្រាស់នូវសូចនាករមួយចំនួន ដែលអាចជាប់ទាក់ទងដល់ការប្រែប្រួលបរិមាណសរុបនៃសារពន្ធប្រភេទ និងភាពងាយស្រួលក្នុងការប្រមូលព័ត៌មាន។ ការស្រាវជ្រាវបន្ថែមគឺជាកត្តាចាំបាច់ដែលតម្រូវឱ្យមាននៅក្នុងការចុះអង្កេតលក្ខណៈជីវសាស្ត្រ និងតាមដានការផ្លាស់ប្តូរទីតាំងរកចំណីរបស់សត្វ។ ការស្វែងយល់អំពីរបាយរស់នៅ និងការរកចំណីរបស់សត្វ ពីតំបន់ព្រៃកទាល់ទៅទីកន្លែងបន្តពូជនៃតំបន់មួយទៀត នៅមានកម្រិតតិចតួចនៅឡើយ(ដូចជា ការធ្វើសំបុកពពួកត្រដក់នៅក្នុងភាគខាងជើងនៃប្រទេសកម្ពុជា)។ ភាពប្រែប្រួលសំខាន់ៗនៃទឹក និងប្រព័ន្ធអេកូឡូស៊ីក្នុងតំបន់ទន្លេសាបអស់ជាង២០ឆ្នាំកន្លងមក ត្រូវបានគេរំពឹងថា វាជាផលលំបាកមួយនៃការផ្តួចផ្តើមអភិវឌ្ឍន៍តាមដងទន្លេមេគង្គ។ នាពេលថ្មីៗនេះតាមការវិភាគទឹកទន្លេសាប និងទន្លេមេគង្គបានបង្ហាញថាបំរែបំរួលទាំងនេះអាចធ្វើឱ្យប៉ះពាល់ដល់កម្រិតទឹក និងមានអត្រាកខ្វក់កើនឡើងច្រើន ហើយដែលអាចធ្វើឱ្យដើមឈើនៃព្រៃលិចទឹកដែលធ្លាប់ជាទីជម្រក ធ្វើសំបុកពងកូនរបស់សត្វស្លាប មានការថយចុះយ៉ាងខ្លាំង។ ដូច្នេះការតាមដានត្រួតពិនិត្យអំពីផលប៉ះពាល់ដល់ទីជម្រកសត្វស្លាបទឹកទាំងនោះ ក្នុងឆ្នាំខាងមុខគឺជាបញ្ហាដ៏សំខាន់សម្រាប់ការរួមចំណែកការពារ និងអភិរក្សសត្វស្លាបទឹកក្នុងព្រះរាជាណាចក្រកម្ពុជា។

1. PART ONE: INTRODUCTION

1.1. Conservation Context

The Tonle Sap is the largest lake in Southeast Asia. It is an area of outstanding natural beauty, rich in biodiversity and one of the world's most productive fisheries. The Tonle Sap Biosphere Reserve (TSBR), designated by the Royal Government of Cambodia, contains three core areas, a buffer zone and a transition zone. Prek Toal is one of the three core areas and it is a site of global conservation importance due to the presence of breeding colonies of some of the world's most threatened waterbird species. The Prek Toal bird colonies are the only remaining breeding site in South-east Asia for two Globally Threatened species – Spot-billed Pelican *Pelecanus philippensis* and Milky Stork *Mycteria cinerea* – and the largest remaining site for five more Globally Threatened or Near-threatened species – Oriental Darter *Anhinga melanogaster*, Lesser Adjutant *Leptoptilus javanicus*, Greater Adjutant *Leptoptilus dubius*, Black-headed Ibis *Threskiornis melanocephalus* and Painted Stork *Mycteria leucocephala*.

The conservation significance of these colonies and the urgent need for their protection called for the establishment of a comprehensive monitoring and protection program. The conservation of the Prek Toal core area has been actively managed by the Ministry of Environment of the Royal Government of Cambodia in collaboration with WCS since 2001. The Prek Toal conservation project aims to consolidate management activities and to monitor the success of ongoing conservation and protection strategies. An evaluation of the success of any conservation strategy depends critically on obtaining accurate population estimates and detecting positive or negative trends within the population of conservation concern. Initial population counts from 2001-2003 were incomplete; consequently from 2003 a comprehensive monitoring program has aimed to monitor both the population size of globally significant species and detect annual trends. This program has generated reliable datasets of considerable size for the 2003/4, 2004/5, 2005/6 and 2006/7 seasons. This report outlines the data collection activities at Prek Toal to date, describes the process whereby the data were subsequently analysed and presents the final results of this detailed analysis with regard to the population status of the waterbird colonies. Protection and monitoring of the colonies is ongoing and this report will discuss how the programme should best evolve to reflect our greater understanding of colony dynamics and the effectiveness of current monitoring techniques.

1.2. Monitoring Bird Populations

1.2.1. Why Monitor?

Effective monitoring of the breeding colonies at Prek Toal fulfils a number of interrelated objectives:

- It allows the regional and ***global*** significance of the Prek Toal colonies to be assessed on a species by species basis.
- It allows trends in species' populations to be detected and charted over time.
- Monitoring reports can serve as effective indicators of threats to the birds, both at Prek Toal and throughout their range. For many of the species concerned, Prek Toal is the only major breeding colony in Southeast Asia. Assuming that the colonies at Prek Toal are protected, decreasing population numbers would be indicative of increasing

threats elsewhere in the species' dispersing range.

- The large waterbirds can also function as more general bio-indicator species within the Prek Toal core area. The status of these waterbird populations reflects wider environmental conditions and can be used to identify impending threats such as decreasing food availability, increasing pollution and habitat destruction; all of which could have detrimental impacts across all taxa.
- Monitoring of the waterbirds is linked to management of Prek Toal as it involves the same staff. Therefore obtaining accurate population counts is indicative of effective colony management.

1.2.2. Monitoring Bird Populations at Prek Toal: The Context

There are three distinct types of bird colonies at Prek Toal and they differ from each other in species composition, habitat use and temporal aspects of breeding behaviour:

1. Black colonies – Little and Indian Cormorant, Oriental Darter and Lesser Adjutant. These birds start nesting in August, earlier than other species, and the Lesser Adjutants are the last of them to fledge in March. Peak counts are obtained in December-January. The darters and cormorants nest very densely on >100 trees, whilst the Lesser Adjutants nest sparsely on >50 trees.

2. Black & White colonies – Painted and Milky Stork, Spot-billed Pelican, Greater Adjutant, Lesser Adjutant, Greater Cormorant and Asian Openbill. The pelicans return to Prek Toal in November and are followed soon after by the storks. The majority of Black and White colony chicks fledge in late May, and peak counts of nesting birds are recorded between February and April. This is the largest of the colonies, numbering in excess of 800 trees.

3. Ibis colonies – Black-headed Ibis arrive in January and nest in the scrub around the stork/pelican colony.

4. Satellite colonies – mainly Painted Stork, Lesser Adjutant and Asian Openbill. There were no satellite colonies prior to 2004, with the exception of the long-established Lesser Adjutant colony with the Black Darter colony.

In the wet season and early dry season (until early January) the Black colonies are accessible by boat and during this period it is possible to make a detailed count of each occupied tree. Since this coincides with the peak nesting period of these colonies counts are relatively straightforward. Oriental Darter is the species of greatest conservation significance in the Black colonies, hence the monitoring program has focused on this species as an indicator of overall trends.

Both the main Black & White and the Ibis colonies reach their maximum peak during the late dry season, when the flooded forest in which the colonies are situated becomes virtually inaccessible. Consequently, counts can only be conducted from observation platforms, located in trees at various distances from the colonies, which is much less straightforward than for the Black colonies. The Ibis colonies are the most problematic of all the colonies in terms of monitoring, due to their tendency to occur in the scrub. This makes the Ibis colonies almost impossible to see and no method which enables comprehensive counts has been developed as yet.

The main Black & White colonies are the largest in size and are comprised of the species of greatest conservation significance, particularly Painted Stork, Spot-billed Pelican, Milky Stork and Greater Adjutant, all of which nest in the tree canopy. An additional species, the Asian Openbill, is also included in the monitoring of the main Black & White colonies. Although of lesser conservation concern than the other species, these birds occur at high densities and probably reach sexual maturity earlier than the other stork species. They therefore are an appropriate indicator species, representing the overall status of the entire colony, since they would be expected to increase in population earlier than the other species if conservation interventions were being successful. The distinct colour and large size of all of these key species renders the birds highly visible from the observation platforms, even in trees at a considerable distance away.

Table 1. Key Species Ecology from Birdlife International (2001, updated 2007)

Common and Scientific Name	IUCN Red List Category	Clutch size	Sexually mature *	Estimated Global Population	Distribution
Oriental Darter *Anhinga melanogaster*	Near Threatened	3 to 6	1 to 2 years	Unknown	Bangladesh , Brunei, Cambodia, India, Indonesia, Malaysia, Myanmar, Indonesia, Nepal, Pakistan, Sri Lanka, Thailand . Extinct as a breeder in Lao P.D.R., Vietnam.
Asian Openbill *Anastomus oscitans*	Least Concern	2 to 6	2 to 3 years	130,000	Bangladesh, Cambodia, India, Lao P.D.R. Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, Vietnam
Greater Adjutant *Leptoptilus dubius*	Endangered	2 to 3	4 years+	800-1,000	Cambodia, India (Assam)
Lesser Adjutant *Leptoptilus javanicus*	Vulnerable	2 to 4	4 years	5,000	Bangladesh, Brunei, Cambodia, India, Indonesia, Lao P.D.R., Malaysia, Myanmar, Nepal, Sri Lanka, Thailand, Vietnam
Milky Stork *Mycteria cinerea*	Vulnerable	2 to 3	4 Years	5,500	Cambodia*, Indonesia, Malaysia, Extinct in Thailand and Vietnam
Painted Stork *Mycteria leucocephala*	Near Threatened	2 to 3	4 years	25,000	Bangladesh, Cambodia, India, Malaysia, Nepal, Pakistan, Sri Lanka. Status unknown in Myanmar. Extinct as a breeder in China, Lao P.D.R., Vietnam. No successfully wild breeding birds recorded in Thailand, but a nesting attempt was made in 2006.
Spot-billed Pelican *Pelecanus philippensis*	Vulnerable	2 to 4	3 to 4 years	13,000	Cambodia, India, Indonesia, Sri Lanka. Extinct as a breeder in Lao P.D.R., Myanmar, Nepal, Thailand, Vietnam.
* The Cambodia population is the only known remaining inland/freshwater population.					
Milky Storks have been known to hybridise with Painted Storks in zoos but in the wild the two usually occupy distinct ecological niches.					
The mixed flocks recorded at Prek Toal are an exception in this regard.					
** Based on close relative Dalmatian Pelican.					

In terms of abundance, Oriental Darters, Asian Openbills, Painted Stork and Spot-billed Pelican occur at the highest density. Milky Stork, Lesser Adjutant and Greater Adjutant occur in relatively small numbers (tens or hundreds). The monitoring approach developed here focuses on the more abundant species, however it has been possible to generate approximate figures

for the other three species. These seven species constitute the primary focus of the monitoring program.

1.2.3. Monitoring Wild Bird Populations: The Concept

Ideally a population can be counted with absolute accuracy, and this is sufficient to understand trends in population size. However, for wildlife this is possible only in a small number of cases. At Prek Toal it may be possible to obtain absolute counts for some species in the Black colonies, which are accessible by boat. For most of the other species, however, which are of highest conservation concern, absolute counts are impossible due to incomplete visibility: not all nesting pairs on each tree can be seen and not all colony trees are visible from a platform.

For species that cannot be accurately counted within the entire study area the population must be obtained through **estimation** – sampling a proportion of the population and extrapolating the estimated density over the entire area. This is analogous to sampling primate populations through transect counts, and extrapolating these to give an area density. Within the sampling area the *detectability* of the species must be assessed – i.e. the proportion of individuals that can be counted. Observer error (or bias) also needs to be measured, for example by conducting multiple independent counts of the same birds in a short period of time, to ensure that different observers are giving consistent results.

At Prek Toal, the appropriate sampling unit is a colony nesting tree and the dependent variable is either the number of adults, chicks or nests on the tree. Of these, the number of nests (hatched and being incubated combined) is the most stable. The number of adults present continually fluctuates through the day and depends seasonally on the nesting stage. Chicks are generally easy to identify when small but can become progressively more difficult to separate from adults as they grow. In order to estimate observer error, and natural variation in the number of adults and chicks, independent counts are taken at the peak of the breeding period.

The variance of the population estimate is dependent on the variance in the number of nests on each tree. This takes the form of a confidence interval: e.g. if the 95% confidence interval of the darter colony population size is 450-550 pairs, it means that we are 95% sure that the true population size lies between these limits. The confidence interval also allows us to detect significant changes in population size (those greater than would be expected by chance).

Accurate counts are only possible for a proportion of occupied nesting trees. For large colonies or species with large populations, it is to be expected that random changes in the colony shape will logically result in a different proportion being visible from the fixed-location platform in different years. This proportion therefore has to be recalculated annually in order to estimate the population size. In addition, some trees are visible from more than one platform which results in duplicate counts being made of a certain number of trees: these trees have to be identified and estimates adjusted accordingly.

Therefore, in order to estimate the population size for each species, the monitoring program was designed to take into account the following key factors:

- the average density of nests, chicks and adults on visible trees
- observer variability, through independent counts of the same visible trees
- counts need to be adjusted to account for duplicate counting of the same trees
- the overall size of the colony (number of occupied trees).

Three distinct methodologies were employed to collect data pertaining to each of the above factors and to undertake the relevant analysis of the data. These methods were:

1. **Counts** from fixed platforms of birds and nests on visible trees.
2. **Tree mapping and marking** in order to calculate the number of visible trees, to obtain independent counts by different observers of these trees, and to identify trees that are counted from more than one platform.
3. **Aerial surveys** to estimate the overall extent of the colonies.

Following the collation and detailed analysis of these datasets it has been possible to calculate two key parameters which represent the most integral objectives of any wildlife monitoring regime. These are:

1. **Accurate population numbers. This provides information on the significance of the Prek Toal colonies (*x*% of the world's population).**
2. **An evaluation of population trends over time, in order to assess the success of conservation activities.**

2. PART TWO: METHODS

2.1. Platform Counts

2.1.1. Origins of bird counts

Initially (2001-2003) conservation activities consisted of forest patrols carried out by up to 25 rangers, depending on the season. The rangers used a network of semi-permanent vantage platforms ('*rien*') located at the top of trees for surveillance activities and also to count nesting birds. Although this method allowed for the partial monitoring of the colony area, there was no measure of the percentage of the colony that could be seen from the platforms, or of parts of the colonies that were inadvertently counted more than once. The ranger platform-based counts did, however, prove to be an extremely efficient protective mechanism and resulted in an almost complete cessation of egg and chick collection incidences. The colony protection facilitated by these counts, from both poaching and disturbance, has remained an essential consideration in the development of the monitoring programme. As the programme evolved the platform counts continued to form the basis of the monitoring regime but since 2003 these counts have been supplemented by the tree marking and aerial survey components.

2.1.2. Observation platforms

The bird colonies are initially located by boat at the end of the wet season, from August to January. The rangers use their knowledge of the area and the previous year's records to identify the colony sites, including any new satellite colonies which have been established. The platforms are built in tall trees which allow a good view of the colonies and are situated close enough to permanent streams to facilitate access in the dry season. Suitable trees are selected as close to the colony as possible without causing disturbance. The fact that the birds actually began nesting on one of the platforms in 2005 indicates that the presence of the rangers causes minimal disturbance to the birds. Boats do have access to the core area during the wet season and are potential sources of disturbance to the colonies, often unintentionally. To avoid this, colony boundaries are demarcated using brightly coloured string and warning signs. These signs are also useful when counting the birds, as they help to identify the colony boundaries and distinguish groups of trees that should be counted from different platforms.

2.1.3. Data collection

Colony counts are carried out by the ranger teams two to three times weekly. Pre-formatted data sheets are used when conducting counts, which ensures that data collection and quality is standardised. These counts yield three types of output:

a. Daily colony count datasheet
b. Tree datasheets
c. Weekly summary datasheet.

The daily count datasheet gives detailed information on the colony population and its evolution during the breeding season. This provides the basic raw monitoring data. The datasheets are returned to the station when the ranger teams rotate. This ensures that counts by different teams are **independent** – i.e. the newly arriving team does not know how many birds the previous team counted on each tree. The tree datasheet follows exactly the same format as the daily count datasheet, but serves a different purpose. It maintains a running log of the occupied trees in the colony (but not the number of birds), to assist the new team in locating occupied trees and identifying the occupying bird species. The weekly summary datasheet

simply extracts the daily counts on a weekly basis for each colony. These datasheets are then returned to the Prek Toal Environmental Station when the teams rotate.

2.1.4. Counting procedure

Boat-based counts are used when the water levels are high and the Oriental Darters are breeding. They provide accurate data in a short period of time from all nesting trees and do not require the use of the platforms. For all other species, however, the breeding period coincides with low water levels which render the colonies inaccessible. During this period all counts are conducted from the observation platform using telescopes.

Rangers receive ongoing training to ensure that standardised counting protocols are followed. This allows for the collection of scientifically rigorous data which can be combined and compared over different years. Ranger teams count the trees in order from the platform, tree by tree. Counts always start at the same tree and proceed in the same direction from each platform. They must measure the direction of each tree, estimate the distance to the tree from the platform, identify the tree species, give the tree a number and estimate the percentage of the tree that can be seen from the platform. A ranger team comprises two people, one as the observer and the other as the recorder. The recorder is responsible for completing the datasheet whilst the observer uses the telescope to count the number of birds on each tree. Counts are conducted only when visibility is high and the weather is favourable

On each tree, one species is counted at a time, first the adult birds, then the chicks, the nests with chicks and finally the nests without chicks (parents incubating eggs). Only visible bird species are counted, focusing on the key species: Oriental Darter, Greater Adjutant, Lesser Adjutant, Painted Stork, Milky Stork and Asian Openbill, but including other species where present. The Black-headed Ibis colony is not visible from the platforms and hence is not counted.

2.1.5. Timing of counts

Although the Oriental Darters arrive early (in August), most species arrive much later. Counts are taken throughout the breeding season. However, only data collected during the 6 week period when the species' colonies are at maximum size are used for population estimation and monitoring. During this time the rangers must take extra care to collect the data accurately as the volume of records will increase significantly.

Table 2. Peak Nesting Period for Key Species at Prek Toal

Species	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Oriental Darter												
Pelican												
Greater Adjutant												
Lesser Adjutant												
Painted Stork												
Milky Stork												
Asian Openbill												
Legend		Breeding season					Peak counts					

2.1.6. Data Storage

A Microsoft Access database has been designed by WCS to store data on the platform tree counts. The database has simple on-screen forms for inputting data on the platforms, the nesting trees, the counts made from the platforms and the species seen on the trees.

It currently contains a complete record of all data from 2001-7 for Black colonies and 2003-7 for the main Black & White colonies. These total 2,878 counts, 4,056 trees and 145,425 species records

2.2. Tree Mapping and Marking

2.2.1. Visible Trees

Photograph 1. Tree Marking at Prek Toal

Tree mapping and marking is required in order to calculate the number of occupied trees seen from the platforms, and to resolve the problem of multiple counting of the same tree. By marking the trees it is also possible to improve the quality of the platform-based counts, as trees are uniquely identified by a large visible zinc number. Tree mapping and marking is conducted by boat during the wet season following the breeding season (August-November), and is completed before the pelicans return (November). At this time of year the colony is effectively unoccupied.

The tree mapping is carried out by at least two ranger teams. One or more teams use boats to find and attach numbers to the trees; they are directed by another team that remains on the platform with a compass and telescope.

The boat team(s) record the tree number, species, GPS waypoint number and the UTM easting and northing of every tree that is mapped. Trees are

mapped in the same order as they appear on the tree datasheet from the previous season. If possible, a large zinc number plate is attached to the tree facing the platform, otherwise a small lead number plate is attached. It is not possible to attach numbers to some trees and so, although they are *mapped*, these trees are not *marked*.

Sometimes the rangers arrive at a tree that already has a zinc plate or lead plaque belonging to another platform. In this case they attach a second zinc plate facing the second platform from which it was counted. They also record on the tree mapping datasheet the other numbers present on the tree, and the platforms these numbers are associated with. These trees are therefore counted from more than one platform. In 2004/5, 2005/6 and 2006/7 the rangers also checked all trees previously marked with a zinc plates in order to replace lost or damaged marks. Previously mapped trees can easily be located using the GPS coordinates obtained during the previous season.

2.2.2. Invisible Trees

It was also possible, through the boat surveys, to identity a number of trees which were occupied by birds but which were not visible from the platforms. In 2003/4 the ranger teams attempted to map these invisible trees but it subsequently became apparent that boat surveys alone were insufficient to map all occupied trees. In the following years aerial surveys were carried out and the focus on locating invisible trees on the ground diminished accordingly. However, since no aerial survey was conducted in 2003/4 this invisible tree mapping represents the only available data on total colony size for that year.

2.2.3. Darter Colonies

For the Oriental Darter colonies it is impossible to mark the trees because the birds return very early in the season (August), before the Tonle Sap water level has risen sufficiently to allow boat access. For these colonies the rangers use a 1000-metre rangefinder to measure the distance and a compass to measure the bearing from the platform to the trees when the birds are counted. This allows the nesting trees to be accurately mapped. Sometimes nesting trees are located beyond the 1000 metre capacity of the rangefinder, in which case the trees are recorded as being >1000m distant.

2.2.4. Mapped and Marked Trees

Table 3 shows the number of mapped and marked trees from the 2003/4, 2004/5 and 2005/6 seasons. More trees are mapped each year as the colony expands or changes location. However, because the birds generally re-use trees nested on in previous years, the proportion of new trees each year decreases. Since the bulk of the colony trees have already had plates attached, the number of newly marked trees is expected to remain relatively low in future years. A total of 1,358 trees have now had metal (zinc or lead) number plates attached (Table 3).

Table 3. Summary of mapped and marked trees from boat surveys 2003/4-2005/6

Year	2003/4	2004/5	2005/6	Totals
Total Mapped Trees	1,158	591	232	**1,981**
of which -				
Invisible	431	85	2	**518**
Visible	727	506	230	**967**
Total Marked Trees	559	577	222	**1,358**
of which -				
Marked with Zinc	559	477	220	**1,256**
Marked with Lead	0	100	2	**102**

2.3. Aerial surveys

2.3.1. Flights

Aerial surveys were conducted in 2004/5, 2005/6 and 2006/7 in order to estimate the extent of the colony – the number of total occupied trees (visible and invisible). This was achieved by taking a complete set of overlapping aerial photographs, which were then georeferenced allow the precise area occupied by the colony to be estimated. The photographs were taken from the base of an aircraft, flying at 2,500 feet on transects separated by 250 metres.

The surveys were conducted in late March or April of each year when the colony was at its maximum extent. In the first year, 2004/5, two flights were required to refine the method. In subsequent years, 2005/6 and 2006/7, a single flight of 5 hours was required to complete the survey. All flights were conducted using the Cessna aircraft flown by Mission Aviation Fellowship Cambodia.

2.3.2. Technical Setup

The entire flight data collection was designed to be controlled by a laptop computer. This automates data collection, reducing the possibility of human error and loss of data.

A Nikon D70 digital camera was used to obtain the photographs at 3008 × 2000 pixels. The camera was controlled using the Nikon Capture 4 software on the laptop computer. This allows the camera clock to be synchronised with the laptop's clock – which is set to Greenwich Mean Time. Photographs were taken using the time-lapse photography option in the Nikon Capture 4 software, using a delay of 8 seconds (s) between pictures. This means that it was only necessary to start the camera at the beginning of each transect and to pause it at the end – with photographs being taken continuously along the transect. The software automatically copies the photographs to a designated directory on the laptop computer, so that disk space is not a limiting factor (i.e. there is no need to change the digital camera card). Photographs can be viewed shortly after they were taken on the laptop screen to ensure that data of sufficient quality is obtained.

A Garmin 12 XL GPS was used to obtain latitude and longitude co-ordinates. The GPS was also controlled from the laptop using the GPS Utility software. The 'Track Real Time Position' was used to plot the aircraft's position every second. This GPS track was saved regularly as it was needed for later use to reference the photographs. The Position Console (in GPS Utility) and a map displaying the flight plan

allowed the flight's progress to be continuously monitored.

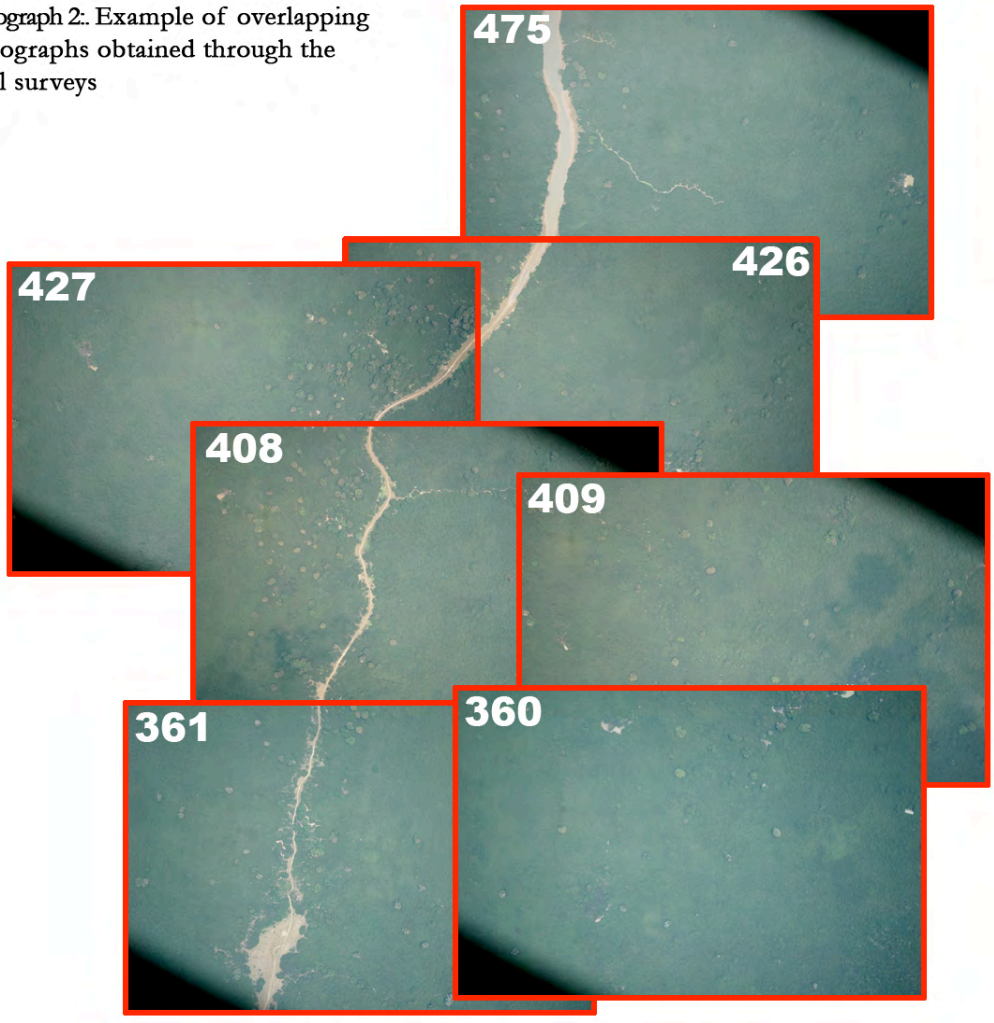
Before the flight a photograph of a GPS clock was taken by the Nikon D70 digital camera in order to allow later synchronisation.

2.3.3. Flight Plan

The flight plan assumed that the aircraft was flying at 2,500 feet (763 metres), at a speed of 150km/hr. This was an appropriate altitude given the risk of low elevation cloud during the survey period. At this altitude, with a camera focal length of 35mm, the photographs measured 516 × 340 metres with a pixel size of 17 × 17 cm. The choice of focal length and altitude were particularly important as these determine the photograph size, whilst the flight speed and time-lapse setting determine the frequency of photographs along the transect.

The photographs were timed to ensure a minimum of 30% overlap between sequential pictures. The time-lapse photography was set to 8s, or every 333 metres flown (assuming a speed of 150km/hr), an overlap of 55% in the photograph length. Similarly, flight transects were placed 250 metres apart, an overlap of 36% in the photograph width. This ensures that a complete over-lapping sequence of photographs was obtained.

Photograph 2:. Example of overlapping photographs obtained through the aerial surveys



With a spacing of 250 metres, approximately 30 transects were required to cover the main nesting colonies each year. Given that the aircraft required a minimum of 1km to turn after completing a transect, the flight plan assumed an average turning width of 1.5-2km. Accordingly a complete survey required 9-10 loops over the main colonies. A small number of additional transects were required each year to cover satellite colonies.

3. PART THREE: ANALYSIS

The following distinctions with regard to terminology may clarify the tree mapping analysis.

Counted Trees: All trees counted from the platforms. Not adjusted for multiple-counted trees.
Visible Trees: Actual number of occupied trees visible from the platforms. Adjusted for double and triple-counted trees. Not all visible trees are mapped or marked.
Invisible Trees: Trees which are occupied by birds but are *not* visible from the observation platforms and are not counted. These trees are identified during the course of the boat surveys subsequent to the birds dispersing from Prek Toal or by aerial surveys.
Occupied Trees: Trees with nesting birds. Total of both invisible and visible trees.
Mapped Trees: Trees which have been visited by the boat survey team and had GPS coordinates of their position recorded.
Marked Trees: A subset of mapped trees. Tree to which the boat survey team has been able to attach a zinc or lead number.

3.1. Selection of Platform Counts

3.1.1. Data Selection Criteria

Estimating population numbers for the colonies requires analysis of a proportion of the annual data collected at Prek Toal. Between 25,000 and 30,000 individual counts of species on trees are made each season at Prek Toal: an enormous volume of data. This volume of data obtained is a consequence of the monitoring and protection system. In any one week up to 25 rangers are carrying out two or three counts of eight different species from up to 15 active platforms. As explained previously, this monitoring and protection system is essential for the effective management of Prek Toal, through deterring collection of the birds and eggs.

Only a small proportion of the data actually needs to be analysed to estimate the average number of pairs on visible trees. The data selection process ensures that the data used in this analysis is as representative and as accurate as possible. Potential sources of error and bias must also be investigated and controlled for. The data were initially examined for the following:

1) The presence of a distance effect: How does the average number of nests per tree change according to the distance of the observation platforms?

2) Inter-observer variation: Do the results of the counts of number of nests per tree differ significantly between observers?

The total number of nests observed was taken as the independent variable throughout the data analysis process. The number of nests is calculated as the number of nests with visible chicks or eggs and it is assumed each nest corresponds to one breeding pair of adults. Following these preliminary tests a set of peak surveys were selected for each species at each platform. These final data were subjected to further detailed analysis with regard to population trends and final population estimates.

3.1.2. Distance Effect

In order to determine whether or not a distance effect was present it was necessary to conduct analysis on a subset of the dataset. The Spot-billed Pelican and Painted Stork data from the 2005/6 season were selected for this purpose as these are the highest density species of conservation significance. A total of 32 survey dates were chosen to represent the two species, 17 surveys for Painted Stork and 15 for Spot-billed Pelican. All of the surveyed trees were assigned a distance category, with each category covering 250m and the effect of distance was investigated using analysis of variance.

Distance between the trees being counted and the observation platform was not found to have significant effect on the mean number of nests observed for either species (Painted Stork $F_{1,702} = 0.067$, $P > 0.05$, Spot-billed Pelican $F_{1,396} = 0.064$, $P > 0.05$). However, the rangers are counting trees up to 3000 metres from the platform, a far greater distance than anticipated. As evident from Figs 1 and 2, the variance around the mean nests observed increases considerably at around 2500m. This suggests that nests can be accurately counted up to 2500 metres from the platform, after which the error increases considerably.

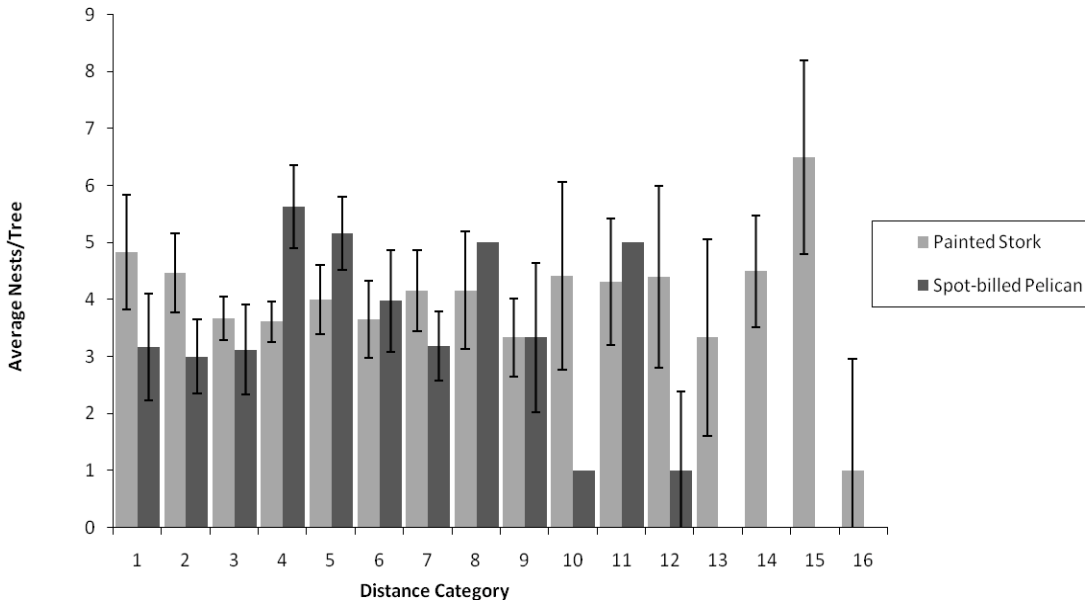
Table 4. Analysis of Variance result for the effect of distance on the number of Painted Stork nests observed

Painted Stork 2005					
Source	d.f.	SS	MS	*F*	P
Distance Categories	1	0.474	0.474	0.067	0.795
Residual	702	4945.899	7.045		
Total	703	4946.374	7.036		

Table 5. Analysis of Variance for the effect of distance on the number of Spot-billed Pelican nests observed

Spot-billed Pelican 2005					
Source	d.f.	SS	MS	*F*	P
Distance Categories	1	0.756	0.756	0.064	0.801
Residual	396	4700.540	11.870		
Total	397	4701.296	11.842		

Figure 1. Average number of nests observed in distance categories of 250m from the platforms. Displays confidence interval of 95%.



3.1.3. Observer Comparisons

Different observers were compared by identifying independent counts of nests with chicks and/or nests with eggs carried out by a pair of different surveyors. Each pair of observers counted the same trees, from the same platform, in the same order on different days. Surveys for analysis were selected using 2 key criteria:

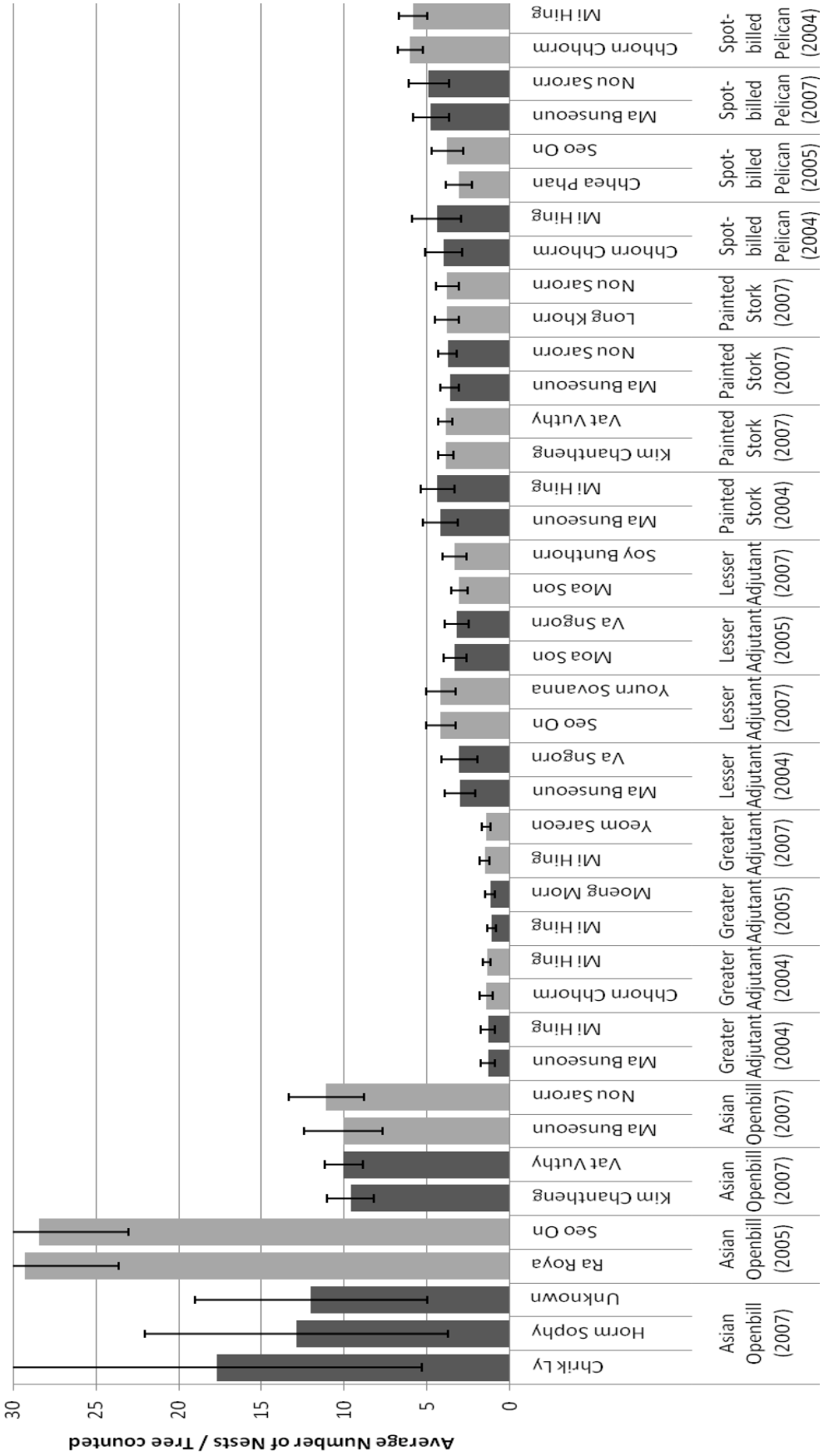
1. The temporal proximity of the survey carried out by Observer A to that carried out by Observer B. Numbers of nests is known to remain relatively stable over the course of a few days and by choosing surveys as close together as possible it was ensured that the natural variation in nest numbers was minimised. Thus differences in the two surveys reflect differences in the nests observed rather than the nests present on the trees.
2. The presence of large number of nests on the trees, to ensure sufficient volumes of data for analysis.

This meant that the surveys used were mostly taken from the peak nesting period and were carried out no more than 4 days apart, with the exception of the Greater Adjutants, for which surveys up to 7 days apart were selected. A number of trees in each survey were recorded as having adults present but not having chicks or nests present for either survey. These adults were presumed to be transitory rather than nesting birds and these trees were excluded from the analysis. In cases where a tree was recorded by Observer A as having nests but was not recorded at all by Observer B, these trees were added into Observer B's data as having zero nests. A total of 41 paired surveys were selected from 2004, 2005 and 2007 – that is 4 paired surveys for each species (and one group of three surveys for Asian Openbills). The pairs of surveys were taken from different years and included as many of the rangers as was possible while meeting the above criteria. The data were analysed in a one-way analysis of variance, and the effect of observer was not found to be significant ($F_{15,\ 1520} = 0.381$, $P > 0.05$). This indicates that observers are counting the colony consistently.

Table 6. Analysis of Variance for the effect of Observer on number of nests recorded

Observer Comparison					
Source	d.f.	SS	MS	*F*	P
Observer	15	1.777	0.118	0.381	0.984
Survey	16	229.054	14.316	46.046	0
Residual	1520	472.574	0.311		

Figure 2. Comparison of Different Observers for Five Species. Confidence Intervals are shown.



3.1.4. Identification of Peak Surveys

Different platforms and species have different peak nesting times, depending upon the timing that the birds arrived at each location. The peak nesting period is defined as counts from 2-6 weeks when the colony is at its maximum extent and the number of nests recorded is high and constant. During this peak period one survey is selected for each of the key species from each of the platforms they are counted from. The survey is selected on the basis of having the highest count of nests (either nests with chicks or nests with eggs and chicks) and should fall in the centre of this peak time period. Atypically high nest counts and sudden spikes in numbers, especially when recorded outside this peak time period, are considered suspect in terms of data quality and thus are not selected. The average number of nests per tree, corresponding to the average number of breeding pairs per tree, can then be calculated using these peak surveys.

3.2. Tree Mapping and Marking

3.2.1. TSEMP Orthophotos

In order to analyse the tree mapping data a considerable amount of GIS processing was undertaken. The Tonle Sap Digital Orthophoto Maps were used as the basic underlying layer for all of this processing. These orthophotos were produced by the PASCO-FINNMAP consortium under contract to the Fisheries Administration (FiA) of the Ministry of Agriculture, Forestry and Fisheries (MAFF) as part of the Tonle Sap Environmental Management Project (TSEMP). The images include a 1:2,500 colour digital series obtained from 1:12,000 scale aerial photography, covering the three core areas, including Prek Toal (accuracy ±0.60 metres).

3.2.2. The Prek Toal Tree Database

The first step in the tree mapping analysis was to create the Prek Toal tree database using the relevant orthophotos. Those images representing Prek Toal were selected and underwent digital processing. The location of 27,118 trees in and around the core area has been mapped and each of these trees has been allocated a unique master tree identification code. The resulting tree database includes a total of 16,000 trees within the main Black & White colony area, and it is assumed that this represents all of the trees available to the nesting birds. The objective of this process was to enable a comparison, using GIS software (Arcview 3.3), between the trees mapped during the boats surveys each year and the master tree database. Each of the trees mapped and marked on the ground could then be matched to its corresponding tree in the master tree database, thus assigning it the same unique master tree identification code.

3.2.3. Visible Tree Mapping

The location of each visible tree was determined using the Prek Toal tree database. Table 7 shows the number of visible trees mapped within the main Black & White Colony. Data was taken from the platform counts in 2003/4, 2004/5, 2005/6 and 2006/7 for each of the seven key species. Thus it was possible to show the location and number of occupied trees, to adjust the numbers to account for double or triple-counted trees (see section 3.2.4) and to accurately calculate distance between mapped trees and the platforms from which they were counted (see section 3.1.2). It should be remembered that only a proportion of the trees which were counted from the platforms could be located during the tree mapping surveys (63-93%). In 2006/7 no tree mapping was conducted, however the location of a large number of counted trees was known due to the marks attached in previous years, which can be read from the platform. Trees for which an exact location could not be

determined are therefore absent from the visible tree maps.

3.2.4. Double-counted Trees

Double-counted trees were identified by comparing the complete dataset of counted trees for each year with the completed master tree database. Because each of the trees has a unique master ID it was possible to determine exactly how many trees were counted more than once from different platforms. The total number of trees observed from the platforms can then be adjusted to remove the effect of double or triple-counted trees. The number of double-counted trees has remained relatively low, between 6% and 10% of the total number of trees mapped yearly (Table 7). However, this implies that the historical population figures were 6-10% higher than the true figure.

3.2.5. Number of Trees Mapped

The number of counted trees visible from the platforms increased from 2003/4 to 2004/5 by 9% and from 2004/5 to 2005/6 by 10% (see Table 7). Of these trees between 55-78% have been mapped for each year.

Table 7. Summary of the number of trees counted each year within the main Black & White colony. The table shows the number of trees mapped and double-counted. The adjusted number of mapped trees counted is equal to the number mapped minus the number double-counted.

Year	2003/4	2004/5	2005/6	2006/7
Total Counted Trees	660	711	751	783
Number of these trees mapped	469 (71%)	659 (93%)	562 (75%)	490 (63%)
Number of mapped trees double-counted	47 (10%)	60 (9%)	46 (7%)	40 (6%)
Adjusted number of mapped trees counted	422	599	516	450

3.3. Aerial Surveys

3.3.1. Outputs

Each aerial survey produced two associated datasets:

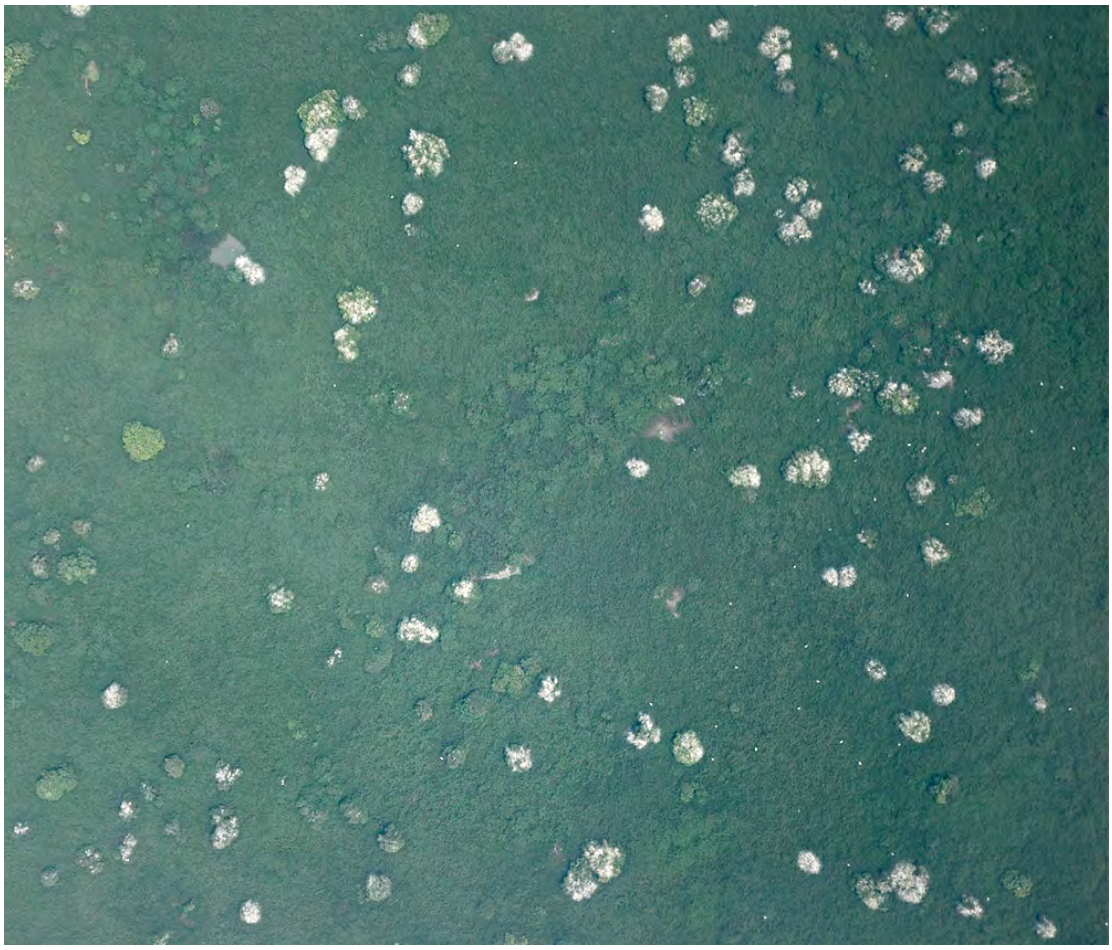
1. A complete GPS-tracklog of the flight, with latitude/longitude points taken every 1-3 seconds.
2. The set of digital photographs taken by the Nikon D70, each of which will be stamped with the date and time it was taken.

Table 8. Summary of aerial surveys 2004/5-2006/7

Year	2004/5	2005/6	2006/7
No. flights	2	1	1
Survey Date(s)	24th March 13th April	21st April	12th April
No. photographs	498 + 906	990	800
Geo-referenced	226 + 127	265	219

3.3.2. Processing of photographs

Photograph 3. Aerial Photograph, showing trees occupied by nesting birds



The central coordinates are obtained by matching the photo time-stamp with the GPS tracklog, using GPS-PhotoLink. A shapefile is then produced containing the coordinates of the central point of each photograph. Finding this central point allowed the photographs to be easily and accurately geo-referenced, using the orthophotos as a basemap (see section 3.2.1). Only photographs with evidence of nesting birds were geo-referenced (Table 8). The resultant sets of geo-referenced images; one for each of the three years, underwent intensive visual processing and all of the trees in which birds were detected were digitised. This allowed the exact location and master tree identification code of each occupied tree to be determined so that the total number of nested trees within the colony could be calculated for each year. A shapefile containing all of these occupied trees was produced for 2005, 2006 and 2007.

3.3.3. Scrub Colonies

The Asian Openbills arrive latest of all the key species at a time when water levels have dropped to their lowest point in the dry season. This means that not only are many of the nesting trees already occupied by other species, but also that large areas of scrub, previously submerged, are now available for nesting. This caused some difficulty when processing the aerial images as the scrub and small trees are not easily discernable, especially when covered by nesting birds. Consequently, only trees identified as present in the master tree database, which was created from the orthophotos, was used to digitise

individual trees. The orthophotos show even small trees, which in turn are represented on the master tree database and this allows them to be distinguished from among the densely packed nesting birds in the aerial images. It is probable that the Ibises have nested in these scrub colonies since 2004.

3.3.4. Coverage

It was anticipated that cloud cover could present a problem if it concealed areas of the colony. In order to access the extent of the cloud cover the entire set of images was viewed simultaneously, using GIS software (Arcview 3.3). Areas of the colony which were obscured by cloud (or were invisible for some other reason i.e. blurred images) *in every available image* were identified and new shapefiles created demarcating them. Due to the amount of overlap between pictures, both sequentially on transects and also between parallel transects, only a very small percentage of the colony area was found to be concealed.

The percentage coverage was calculated for each year by examining the total area concealed by cloud plus the total area of any gaps between images against the total area covered by the aerial surveys. The total area of the colony was defined as the entire area covered by occupied trees with a 500m buffer areas surrounding them. The results (Table 9) show that almost complete coverage was obtained. Consequently, detectability of occupied nesting trees from the aerial photos is expected to be almost 100%.

Table 9. Aerial Survey Coverage

Year	Total area of images geo-referenced (ha)	Gaps (ha)	Cloud (ha)	Obscured (ha)	Covered (ha)	% Coverage
2005	3,387	90	18	108	3,279	96.8%
2006	2,556	68	none	68	2,489	97.4%
2007	3,077	53	47	100	2,977	96.8%

3.4. Estimating the Colony Area for each Species

The total colony size (number of trees occupied) in each year was calculated from the complete maps of digitised trees produced in section 3.3.2. It was assumed that the aerial photo coverage was nearly perfect and that occupied trees can be reliably identified on the aerial photos.

Although occupied trees can be reliably identified on the photos, individual species are difficult to discern. If species at Prek Toal segregate randomly with respect to each other, then species would be expected to be distributed across the colony area and consequently results from the visible trees would be extrapolated over the entire colony area mapped from the aerial photos. However, if species occupy only distinct areas of the colony, these areas must first be identified, and then results from the visible trees extrapolated over the known occupied area.

For 2004, 2005, 2006 and 2007 a large sample of occupied trees have been mapped (see Table 7). It can be assumed that these trees have been selected randomly with respect to the species occupying them, i.e. they were mapped primarily based on ease of recognition from the platform. This sample can then be used to estimate species presence across the colony. The spatial analysis was undertaken using a Kriging, a group of spatial interpolation procedures that generates an estimated surface from a scattered set of points with known values. Kriging involves an interactive

investigation of the spatial behaviour represented by these known values. The techniques were developed by Matheron (1963) based on the Master's thesis of Krige (1951).

For the sample of mapped occupied trees, ordinary kriging was used to interpolate a surface of species presence or absence for the three dominant species in the main Black & White colony: Spot-billed Pelicans, Painted Storks and Asian Openbills. The other species (Greater and Lesser Adjutant and Milky Stork) are not present in sufficient numbers to allow interpolation and are known to segregate with the other three species (see Section 4.3). The main colony area was divided into grid cells 10 × 10 metres and each cell was assigned a probability of species presence, based on the available data from the 10 nearest trees within a 500 metres circular radius. Species presence or absence data was used, rather than absolute abundance, because the aim was to identify areas within the colony where the species was present, not to interpolate abundance.

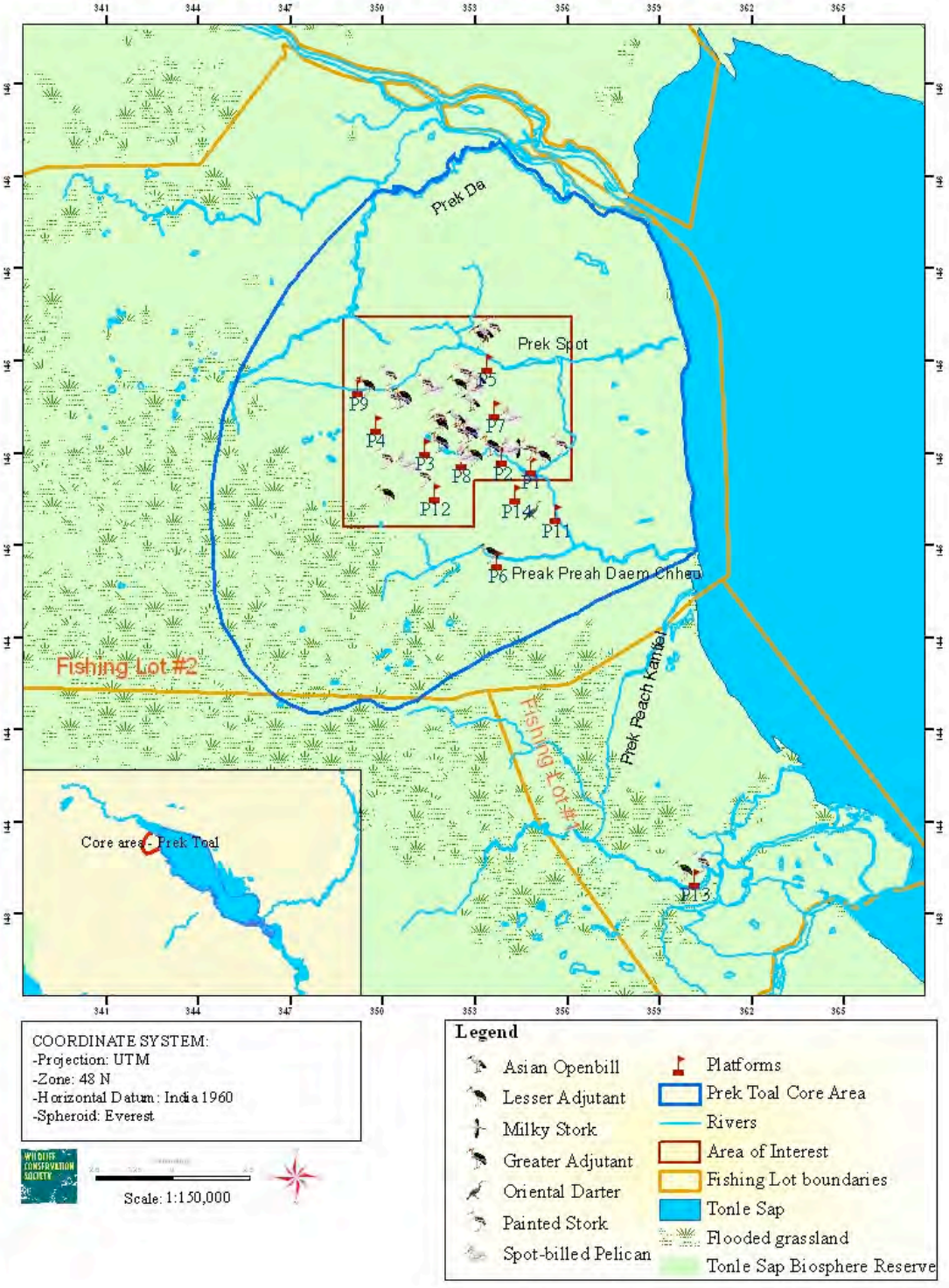
4. PART FOUR: RESULTS

4.1. Colony Evolution

In January 2001, authorities encountered 3 suspicious boats leaving the Prek Toal Core Area Protection. Only one of the boats was intercepted but it contained 1,400 cormorant eggs. This was one of a number of serious collection incidences which prompted start of the conservation program in February 2001. Since then, 8-9 platforms have been in use in the main Black & White Colony, with the birds occupying approximately the same locations each year. Initially just one platform, number 6, 4 km south of main colony, was used to monitor the Black colony. However, as the colony has grown the number of platforms has increased year by year to a current total of 5. The Black colony first began to expand in 2003-4 by occupying new sites just to the south of the main Black & White colony but in 2004-5 it began encroaching into the main colony area for the first time. Currently four platforms are shared by both the Black and the Black & White colonies. Two new satellite colonies were initially detected in 2003-2004 – one of Lesser Adjutants to the north of the main Black & White colony at platform 5 and another of Painted Stork approximately 15km to the south in Fishing lot No. 1. The satellite colonies have since grown in number and complexity and there are currently a number of Lesser Adjutant satellite colonies, including a mixed Painted Stork/Lesser Adjutant colony, and a satellite Asian Openbill colony. Maps 1-4 show the evolution of the colony.

Map 1. PREK TOAL BIRD COLONIES 2002 & 2003

Map 2. PREK TOAL BIRD COLONIES 2004



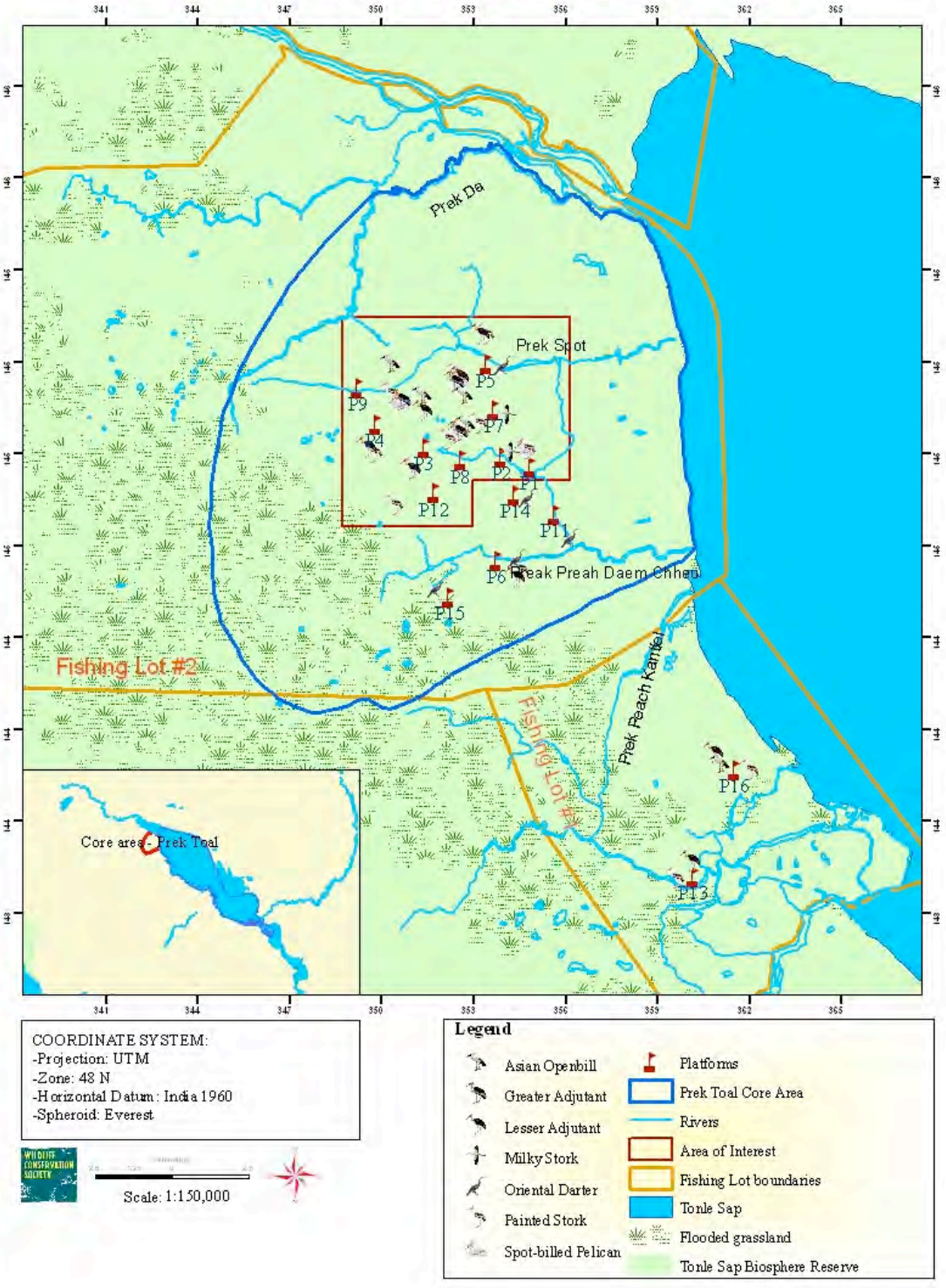
COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

Scale: 1:150,000

Legend

- Asian Openbill
- Lesser Adjutant
- Milky Stork
- Greater Adjutant
- Oriental Darter
- Painted Stork
- Spot-billed Pelican
- Platforms
- Prek Toal Core Area
- Rivers
- Area of Interest
- Fishing Lot boundaries
- Tonle Sap
- Flooded grassland
- Tonle Sap Biosphere Reserve

Map 3. PREK TOAL BIRD COLONIES 2005



Map 4. PREK TOAL BIRD COLONIES 2006 & 2007

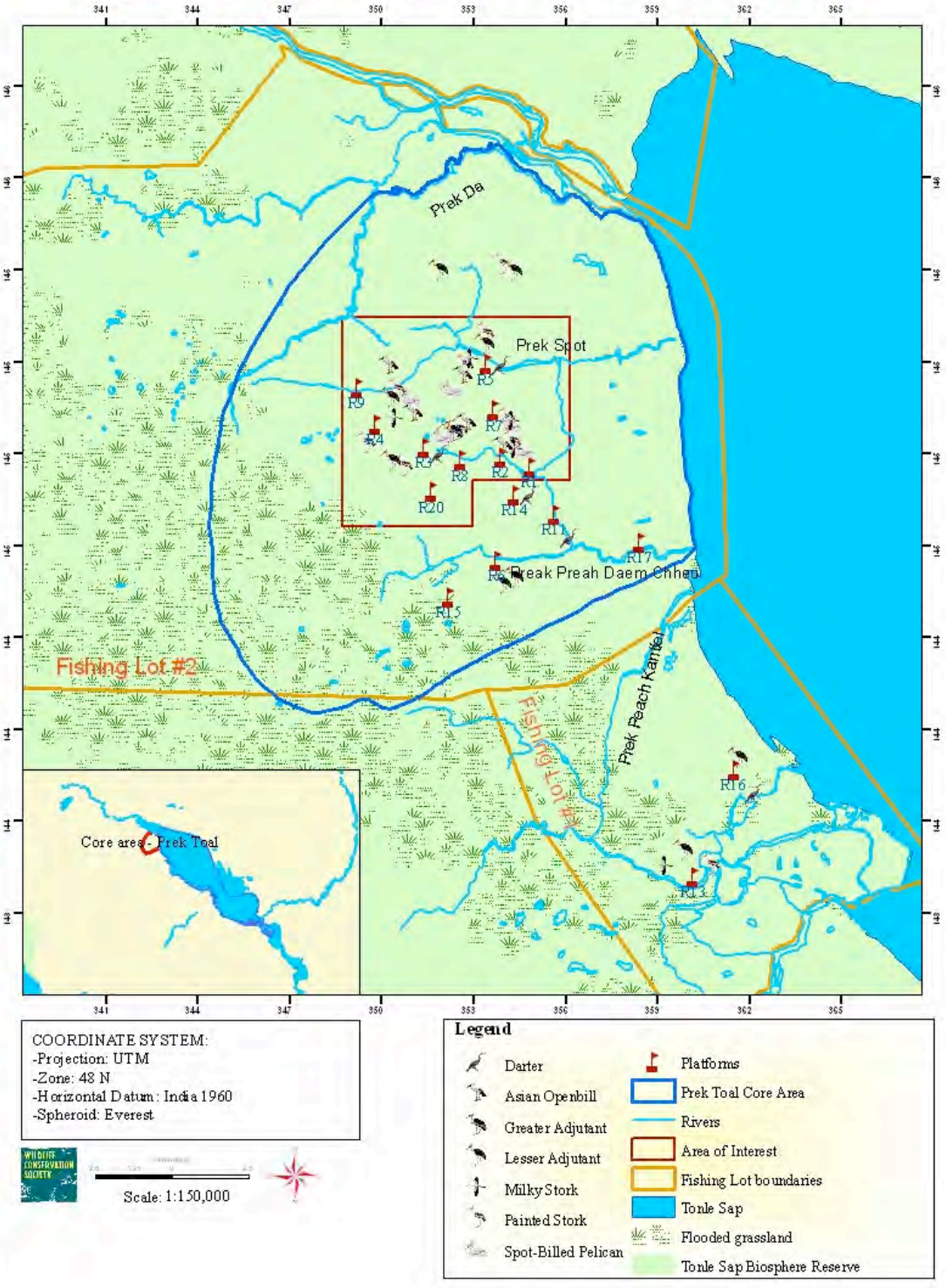


Table 10. Colony Evolution and History

	2000-1	2001-2	2002-3	2003-4	2004-5	2005-6	2006-7
Main Black & White Colony							
Number of Platforms	**5**	8	8	9	9	9	9
Platform Numbers	1,2,3,4,5	1,2,3,4,5,7,8,9	1,2,3,4,5,7,8,9	1,2,3,4,5,7,8,9,12	1,2,3,4,5,7,8,9,12	1,2,3,4,5,7,8,9,12	1,2,3,4,5,7,8,9,12
Start Platform Counts	Feb-01	Dec-01	Nov-02	Nov-03	Dec-04	Nov-06	Nov-06
End Platform Counts	May-01	May-02	May-03	Jun-04	Jun-05	Jun-07	Jun-07
Black (Darter) Colony							
Number of Platforms		1	1	3	5	6	9
Platform Numbers		6	6	6,11,14	5,6,11,14,15	3,5,11,14,15,16	3,5,7,11,12,14,15,16,17
Start Platform Counts		Oct-01	Aug-02	Aug-03	Aug-04	Oct-05	Aug-06
End Platform Counts		Jul-02	Jul-03	May-04	May-05	May-06	May-07
Satellite Colonies							
Number of Locations		1	1	3	4	5	5
Platform Numbers		6	6	5,6,13	5,6,13,16	5,6,13,16,17	5,6,13,16,17
Species		Lesser Adjutant	Lesser Adjutant	Lesser Adjutant, Painted Stork	Lesser Adjutant, Painted Stork, Asian Openbill	Lesser Adjutant, Painted Stork, Asian Openbill	Lesser Adjutant, Painted Stork, Asian Openbill
Start Platform Counts		Oct-01	Aug-02	Feb-04	Jan-05	Dec-05	Dec-06
End Platform Counts		Jul-02	Jul-03	Jun-04	Jun-05	May-06	May-07
Collection Incidents (species affected)	Major	2 Major, 1 Minor (Pelicans)	1 Major (Pelicans)	4 Minor (Darters, Lesser Adjutant, Pelican, Painted Stork)	None	None	None

4.2. Timing of peak counts

Table 11. Peak Nesting Dates

	2002	2003	2004	2005	2006	2007
Asian Openbill			15-Mar-04	4-Mar-05	15-Mar-06	4-Mar-07
Greater Adjutant			24-Apr-04	6-Apr-05	8-Apr-06	18-Apr-07
Lesser Adjutant			21-Apr-04	24-Mar-05	12-Apr-06	22-Mar-07
Milky Stork			25-Mar-04	23-Apr-05	28-Mar-06	1-Apr-07
Painted Stork			10-Apr-04	13-Apr-05	6-Apr-06	15-Mar-07
Spot-billed Pelican			16-Mar-04	16-Feb-05	7-Feb-06	31-Jan-07
Oriental Darter	14-Jan-02	19-Jan-03	07-Dec-03	21-Nov-04	04-Nov-05	08-Nov-06

Table 11 gives a peak nesting date, calculated as a weighted mean date, for each species since 2001 (where data is available). Both Oriental Darters and Spot-billed Pelicans appear to be nesting significantly earlier each year, and a smaller effect is seen for Milky and Painted Storks. The peak date for the other species appears to be relatively constant.

4.3. Species Segregation

Species distribution at Prek Toal shows several discrete trends; they do not disperse randomly with respect to other species. Table 12 shows the number of trees on which a species is the only species present (i.e. is dominant) and the number of trees shared with another species. This analysis is based on the peak visible tree data for each of the years 2004, 2005, 2006 and 2007. Surprisingly, 83.9% of trees from 2004-2007 have only a single species present, i.e. species only share 16.1% of all trees. This shows a remarkable level of differentiation between species spatially in their distribution across Prek Toal. Only Greater Adjutant and Milky Stork show a tendency to share trees with other species, in 67.8% and 100% of trees respectively. Lesser Adjutants may have a tendency to share, but only within the main Black & White colony area. The percentage of trees shared by Asian Openbills has increased as they have expanded into the Painted Stork colony area.

Table 12. Number of Trees where a species is the only species present and trees shared.

	Asian Openbill	Greater Adjutant	Lesser Adjutant	Milky Stork	Painted Stork	Spot-billed Pelican	All Species
Trees where the species is the only species present							
2004	47	18	37	0	252	120	474
2005	64	6	51	0	316	126	563
2006	99	19	73	0	283	130	604
2007	126	8	71	0	315	106	626
Trees the species shares with another species							
2004	4	24	19	2	51	51	75
2005	23	22	32	4	86	66	115
2006	52	25	23	10	102	61	128
2007	42	34	15	7	88	67	123

	Asian Openbill	Greater Adjutant	Lesser Adjutant	Milky Stork	Painted Stork	Spot-billed Pelican	All Species
Percentage of trees where species shares with another species							
2004	8%	57%	34%	100%	17%	30%	14%
2005	26%	79%	39%	100%	21%	34%	17%
2006	34%	57%	24%	100%	26%	32%	17%
2007	25%	81%	17%	100%	22%	39%	16%

The data from 2004-2007 was cross-tabulated to compare the observed values with those that would be expected if species segregated according to the same rules. For example, all species are only observed sharing with Greater Adjutant on 3% of occasions. Therefore, Greater Adjutant would be expected to share with Spot-billed Pelican only on 24 trees (3% of the 727 trees Pelicans are found on), however at Prek Toal they were observed sharing on 81 trees. Highly significant departures ($P<0.001$, chi-squared test) are observed for the following species pairs:

Greater Adjutant and Spot-billed Pelican

Lesser Adjutant and Painted Stork (within the main Black & White colony only)

Milky Stork and Painted Stork (Milky Storks always share with Painted Storks)

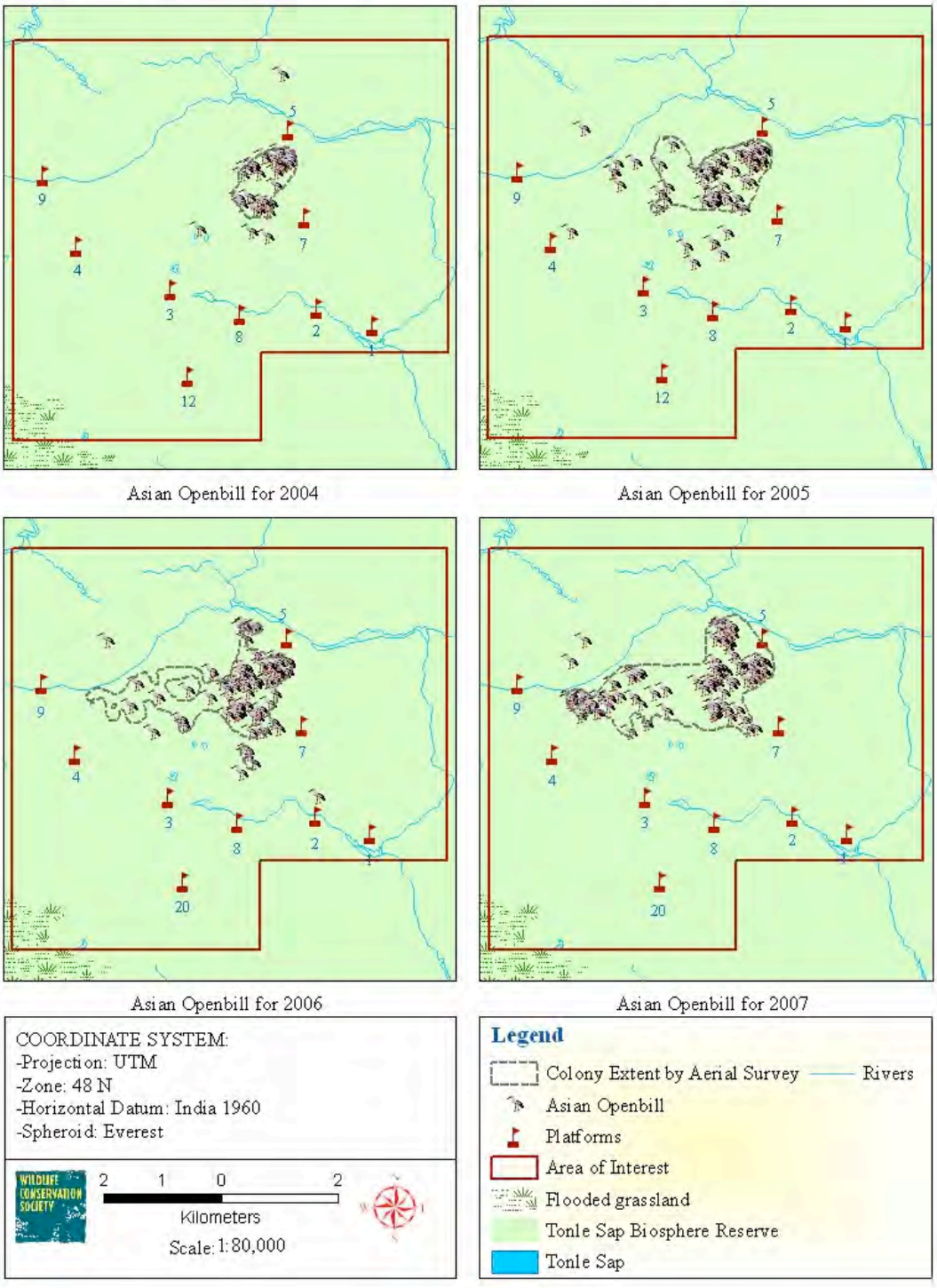
Asian Openbill and Painted Stork (in 2006 and 2007 only, as the Openbill colony expands)

Table 13. Cross-tabulation of the number of trees where a species is dominant (i.e. only species present) and shares with another species, in comparison with the expected values. Shaded shelves indicate where observed data deviates significantly from that expected.

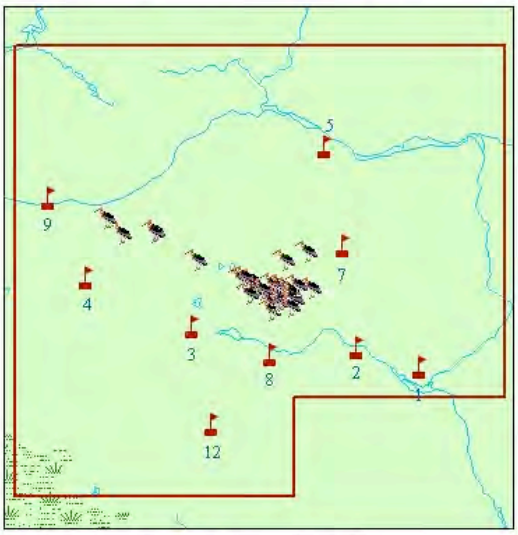
Species		Dominant	Greater Adjutant	Lesser Adjutant	Milky Stork	Asian Openbill	Painted Stork	Spot-billed Pelican
Greater Adjutant	Observed	51		2	0	3	12	88
	Expected	115		4	1	6	16	13
Lesser Adjutant	Observed	233	1		0	1	75	11
	Expected	236	10		2	13	34	27
Milky Stork	Observed	0	0	0		1	22	0
	Expected	17	1	1		1	2	2
Asian Openbill	Observed	336	2	0	0		91	28
	Expected	340	14	12	3		48	38
Painted Stork	Observed	1166	12	73	19	92		131
	Expected	1191	50	43	10	64		134
Spot-billed Pelican	Observed	482	81	9	0	27	128	
	Expected	567	24	21	5	30	81	

Accordingly, the estimated total colony area was only calculated for Spot-billed Pelican, Painted Stork and Asian Openbill (see Section 3.4), because the other species were known to positively segregate with these species. Maps 5-11 show the platforms occupied by each species in 2004-2007 and the estimated total colony area for the Spot-billed Pelican, Painted Stork and Asian Openbill

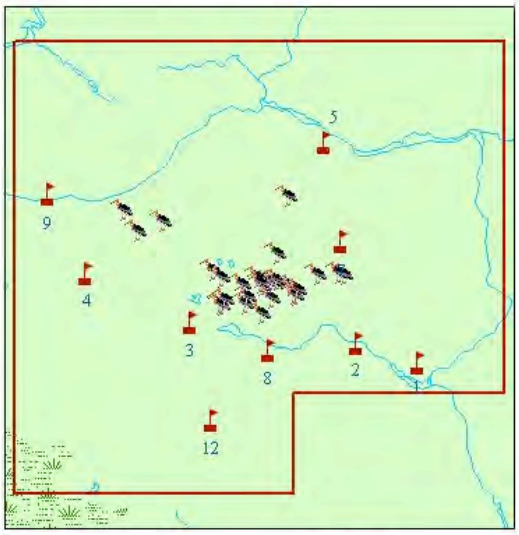
Map 5. Asian Openbill Distribution 2004-2007



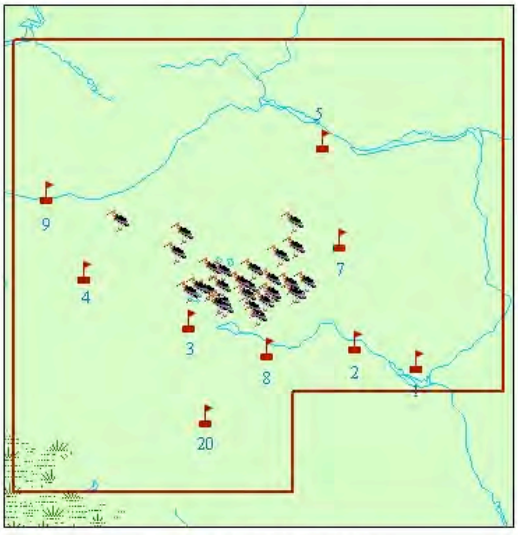
Map 6. Greater Adjutant Distribution 2004-2007



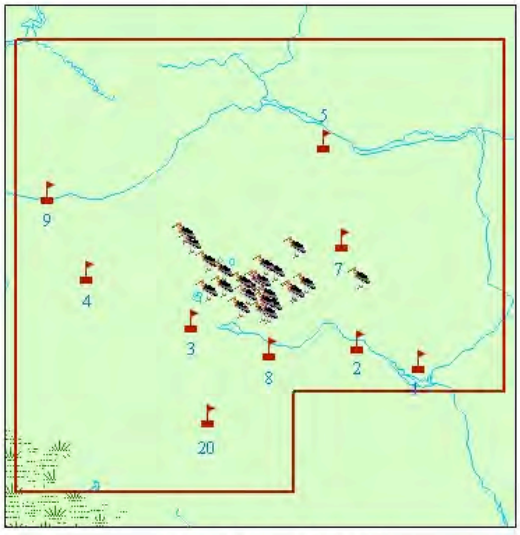
Greater Adjutant for 2004



Greater Adjutant for 2005



Greater Adjutant for 2006



Greater Adjutant for 2007

COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

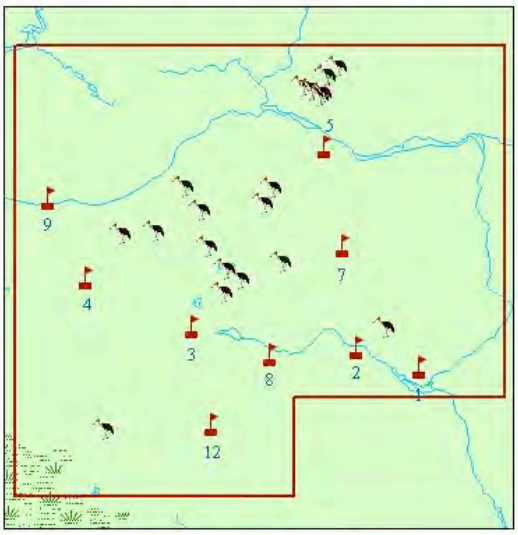
WILDLIFE CONSERVATION SOCIETY

2 1 0 2
Kilometers
Scale: 1:80,000

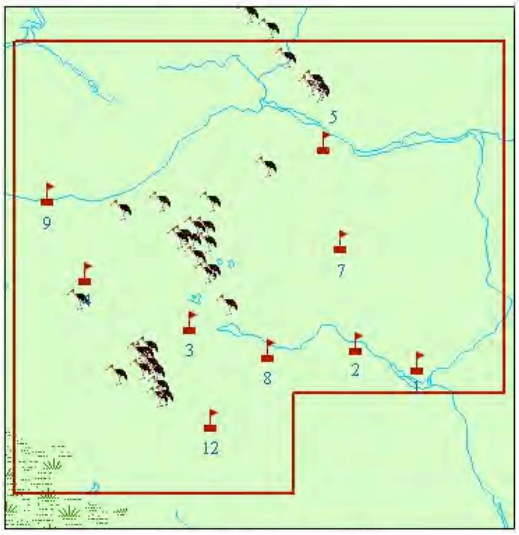
Legend

- Greater Adjutant
- Platforms
- Area of Interest
- Flooded grassland
- Tonle Sap Biosphere Reserve
- Tonle Sap
- Rivers

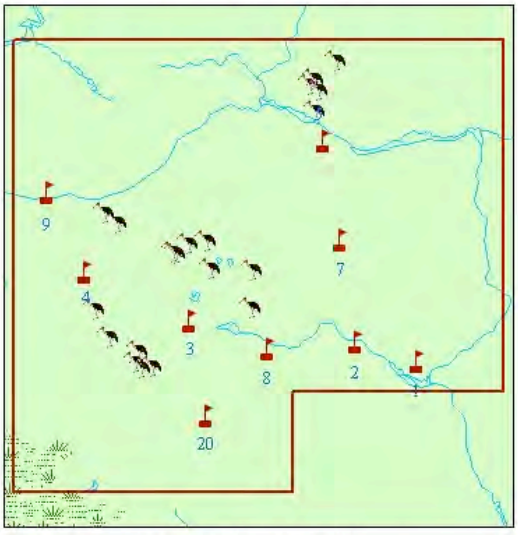
Map 7. Lesser Adjutant Distribution 2004-2007



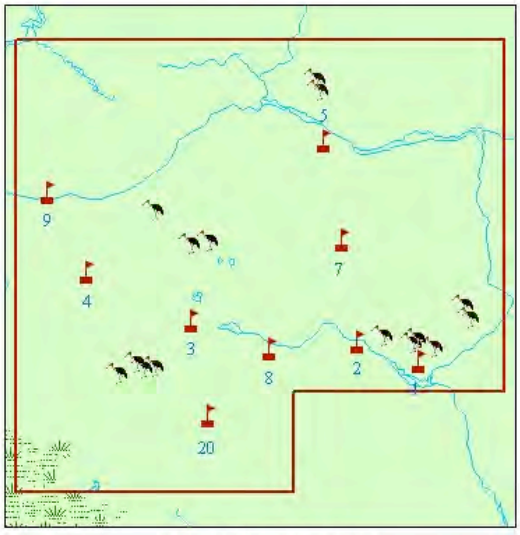
Lesser Adjutant for 2004



Lesser Adjutant for 2005



Lesser Adjutant for 2006



Lesser Adjutant for 2007

COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

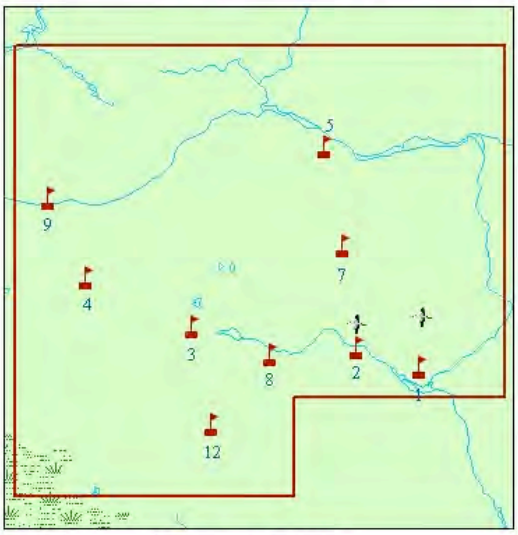
WILDLIFE CONSERVATION SOCIETY

2 1 0 2
Kilometers
Scale: 1:80,000

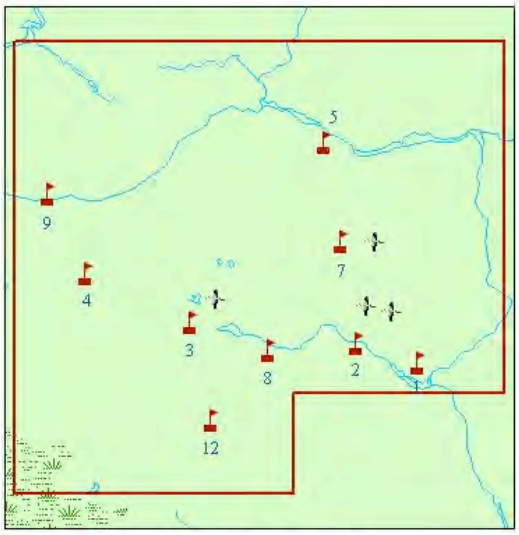
Legend

- Lesser Adjutant
- Platforms
- Area of Interest
- Rivers
- Tonle Sap
- Flooded grassland
- Tonle Sap Biosphere Reserve

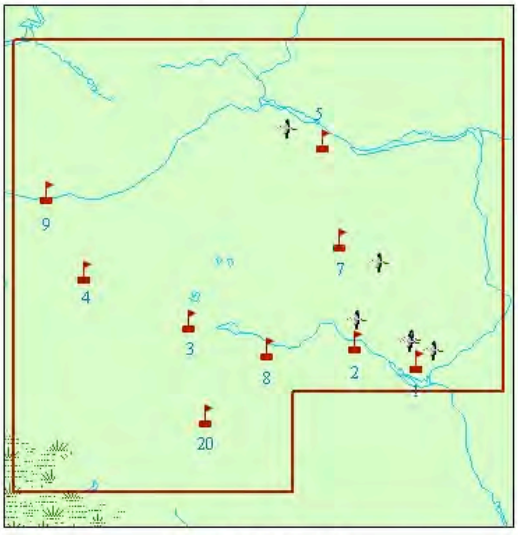
Map 8. Milky Stork Distribution 2004-2007



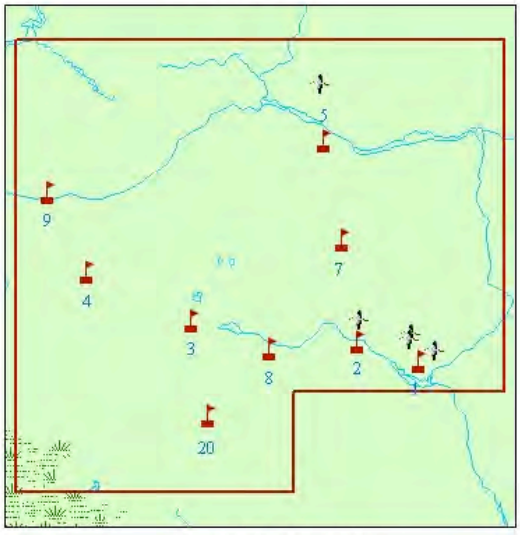
Milky Stork for 2004



Milky Stork for 2005



Milky Stork for 2006



Milky Stork for 2007

COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

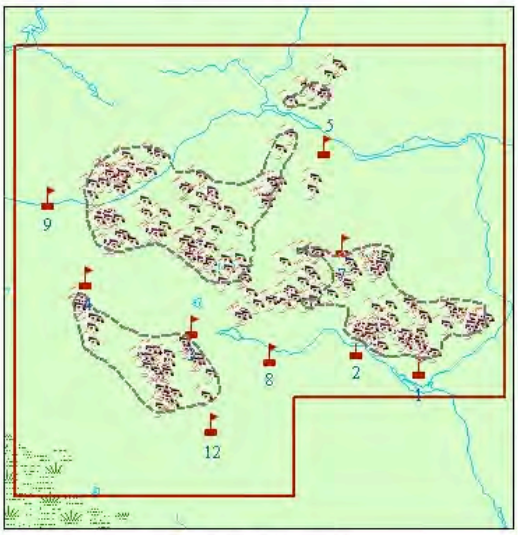
WILDLIFE CONSERVATION SOCIETY

2 1 0 2
Kilometers
Scale: 1:80,000

Legend

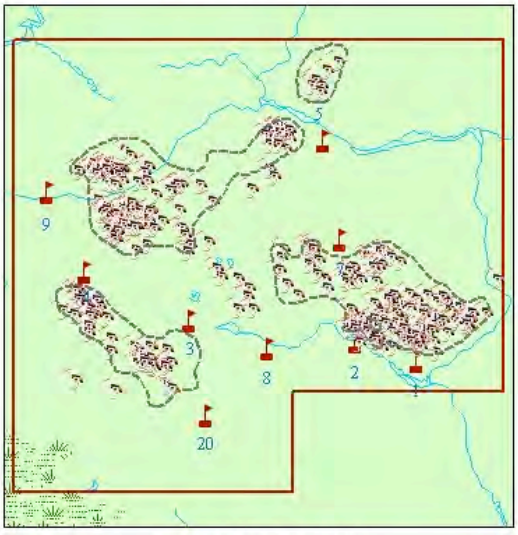
- Milky Stork
- Platforms
- Area of Interest
- Flooded grassland
- Tonle Sap Biosphere Reserve
- Tonle Sap
- Rivers

Map 9. Painted Stork Distribution 2004-2007

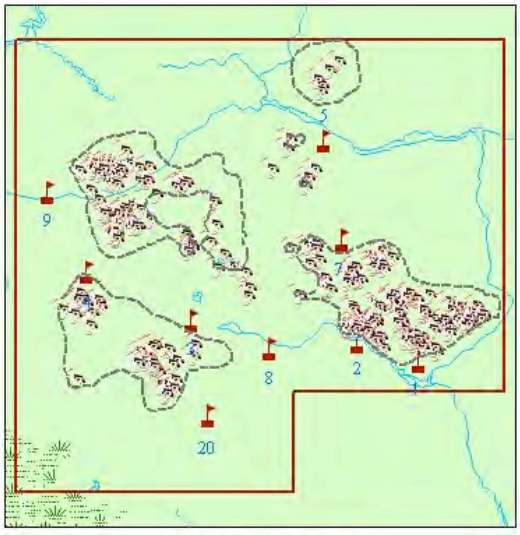


Painted Stork for 2004

Painted Stork for 2005



Painted Stork for 2006



Painted Stork for 2007

COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

WILDLIFE CONSERVATION SOCIETY

2 1 0 2

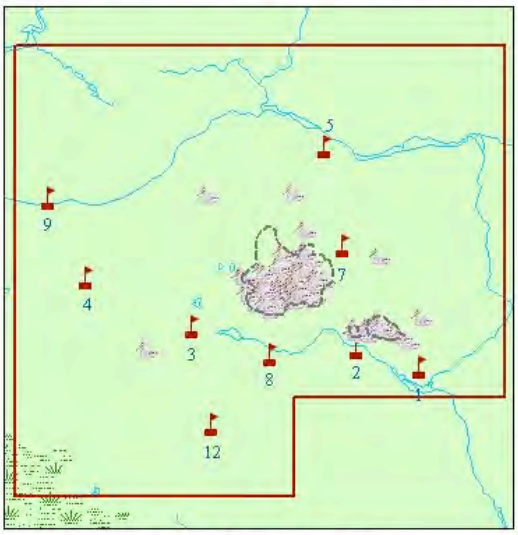
Kilometers

Scale: 1:80,000

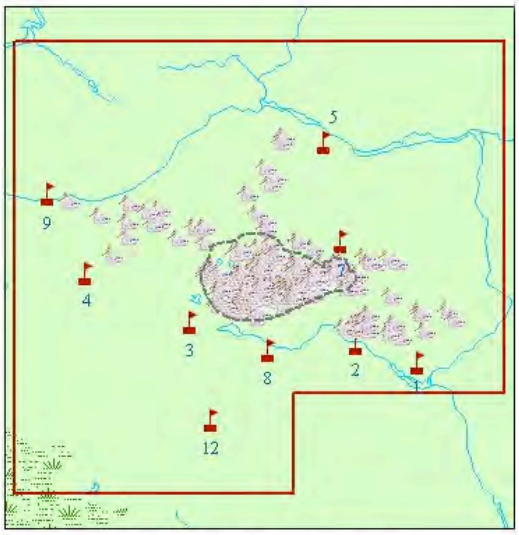
Legend

- Colony Extent by Aerial Survey
- Rivers
- Painted Stork
- Platforms
- Area of Interest
- Flooded grassland
- Tonle Sap Biosphere Reserve
- Tonle Sap

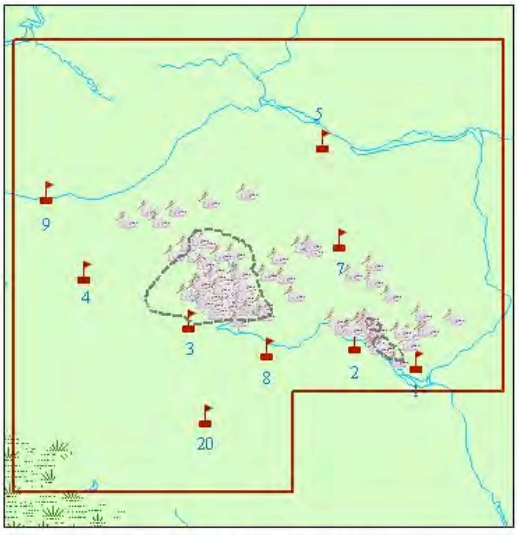
Map 10. Spot-billed Pelican Distribution 2004-2007



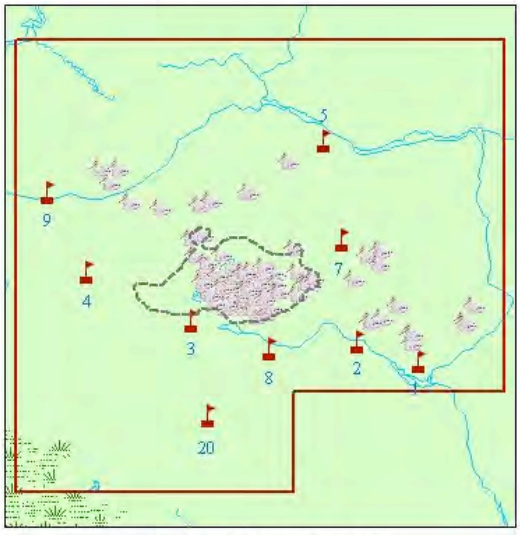
Spot-billed Pelican for 2004



Spot-billed Pelican for 2005



Spot-billed Pelican for 2006



Spot-billed Pelican for 2007

COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

WILDLIFE CONSERVATION SOCIETY

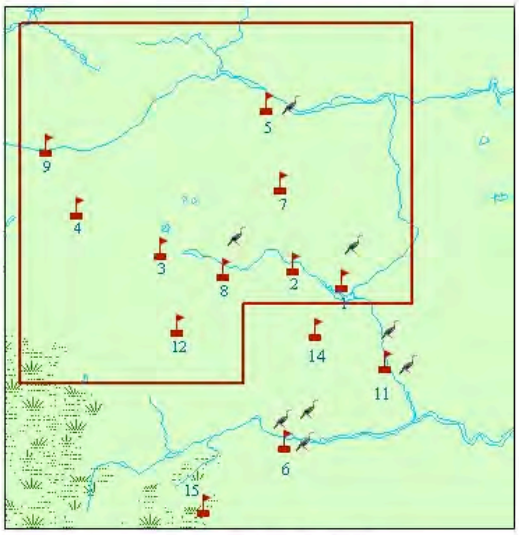
2 1 0 2
Kilometers
Scale: 1:80,000

Legend

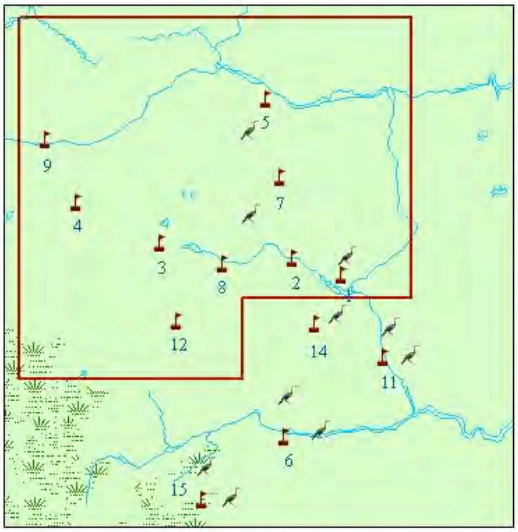
- Colony Extent by Aerial Survey
- Rivers
- Spot-billed Pelican
- Platforms
- Area of Interest
- Flooded grassland
- Tonle Sap Biosphere Reserve
- Tonle Sap

Map 11. Oriental Darter Distribution 2002-2007

Oriental Darter for 2002-2003



Oriental Darter for 2004



Oriental Darter for 2005

Oriental Darter for 2006-2007

COORDINATE SYSTEM:
-Projection: UTM
-Zone: 48 N
-Horizontal Datum: India 1960
-Spheroid: Everest

WILDLIFE CONSERVATION SOCIETY

2.5 1.25 0 2.5
Kilometers
Scale: 1: 100,000

Legend

- Oriental Darter
- Platform
- Area of Interest
- Flooded grassland
- Tonle Sap Biosphere Reserve
- Tonle Sap
- Rivers

4.4. Estimating the Population of a Species

The total population of any species at Prek Toal is equal to:

Total Population =

(Colony 1)
average number of nests per tree **(1)**
×
total number of trees occupied by the species **(2)**

+

(Colony 2)
average number of nests per tree **(1)**
×
total number of trees occupied by the species **(2)**

etc...

With a Standard Error of (using Satterthwaite's approximation for pooled standard errors from samples with different sample sizes):

Standard Error = $\sqrt{\left\{ \right.}$

(Colony 1)
standard error of average number of nests per tree **(1)**
×
total number of trees occupied by the species **(2)**

^{2}

+

(Colony 2)
standard error of average number of nests per tree **(1)**
×
total number of trees occupied by the species **(2)**

^{2}

$\left. \right\}$

etc...

(1) is estimated from the peak surveys from the visible tree data, whilst
(2) is estimated by calculating the number of occupied trees within the colony area for each of the three dominant species (Spot-billed Pelican, Painted Stork and Asian Openbill). The interpolated colony area for each of these species was calculated in Section 3.4.

Each species may occupy one or more colony area, hence the equations describe how these results are combined to estimate the final population size and standard error.

4.5. Visible Trees

4.5.1. Oriental Darters

The easy accessibility to the colony during their peak nesting period and the high visibility of the chicks means that Oriental Darters are relatively easily counted when compared to the other species. The data shown here for visible tree counts therefore constitutes a complete count of all occupied trees

during the peak nesting periods for this species to date and no further analysis is necessary. The monitoring data for the Oriental Darters also differs from data of the other key species in that it includes 2002 and 2003 records in addition to the 2004-2007 data.

4.5.2. All Key Species

Figures 3, 4 and 5 and Table 14 shows the number of counted trees, the total number of nests and the average number of nests per tree as recorded during peak platform surveys for each of the seven key species. Mean number of nests observed per tree has increased steadily and considerably for Spot-billed Pelican, Oriental Darter, Painted Stork and Asian Openbill. The average number of nests has increased slightly for the other species, with some fluctuations.

The total number of nests counted in peak surveys each year has increased dramatically for Oriental Darter and Asian Openbill. The number of nests has increased for Painted Stork, most noticeably in 2005, before levelling off in 2006 and 2007 and for Spot-billed Pelican there was a sharp increase in 2006 followed by a slight decrease in 2007. Lesser Adjutant has shown steady though less pronounced increases in numbers of nests and Milky Stork and Greater Adjutant have also increased each year with the exception of 2005 for Greater Adjutant and 2007 for Milky Stork when numbers dropped slightly. Given that the platform counts only cover a proportion of the colony, which varies each year, these fluctuations in numbers are to be expected, particularly for the rarer species.

In terms of nesting trees counted from the platforms, substantial increases in tree numbers were recorded for Asian Openbill and for Oriental Darter. The number of trees for Greater Adjutant and Lesser Adjutant has remained relatively constant over the years and although the numbers for Milky Stork remain very low in comparison to other species, they have increased since 2006. Counted trees for Painted Stork increased in 2005 and have remained relatively constant since and for Spot-billed Pelican the number of trees peaked in 2005 and 2006 and has dropped slightly since.

Figure 3. Average Number of Nests counted per tree, for colony count data. Confidence Intervals are shown.

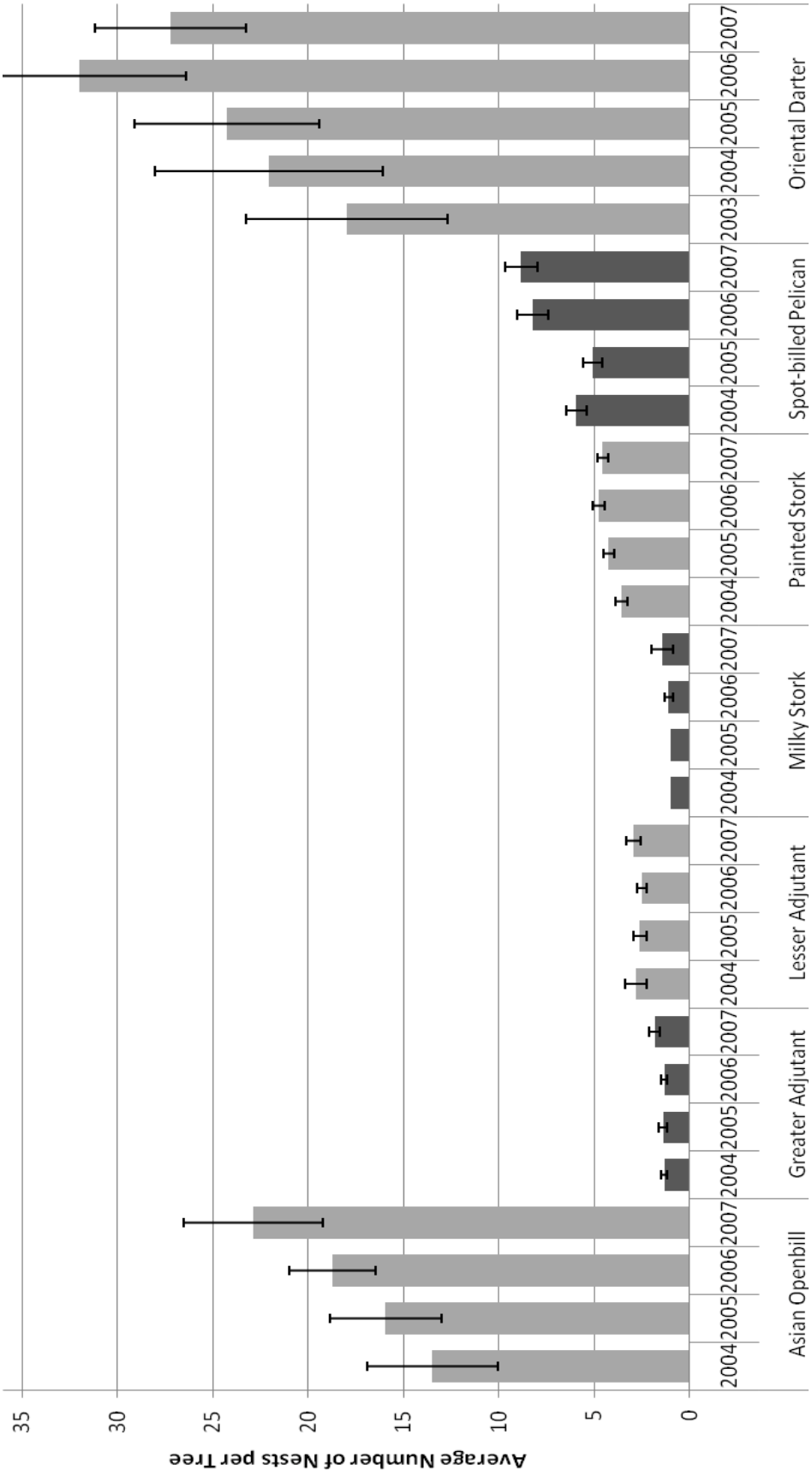


Figure 4. Number of Visible Counted Trees. Confidence Intervals are shown.

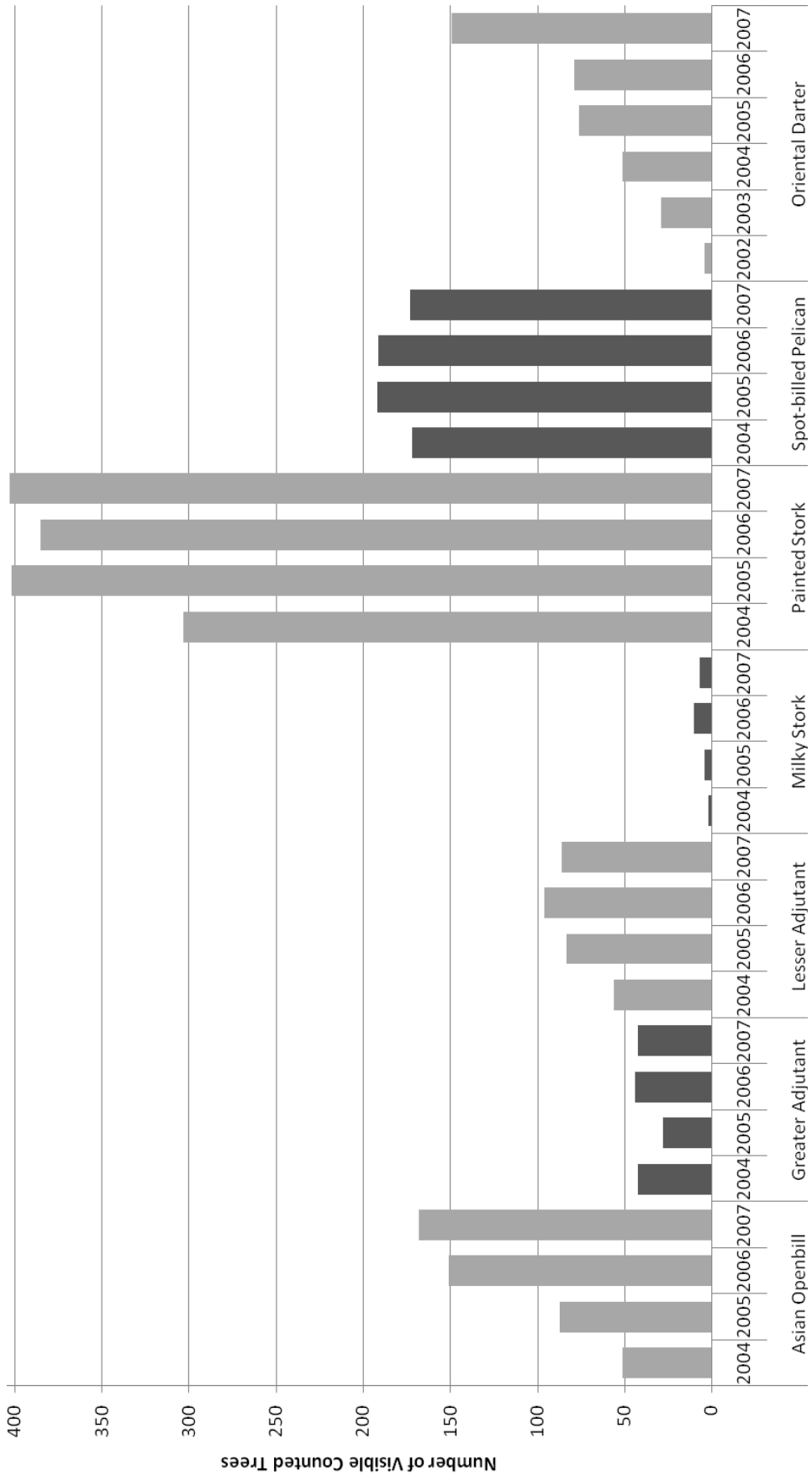


Figure 5. Number of Nests recorded, for colony count data. Confidence Intervals are shown.

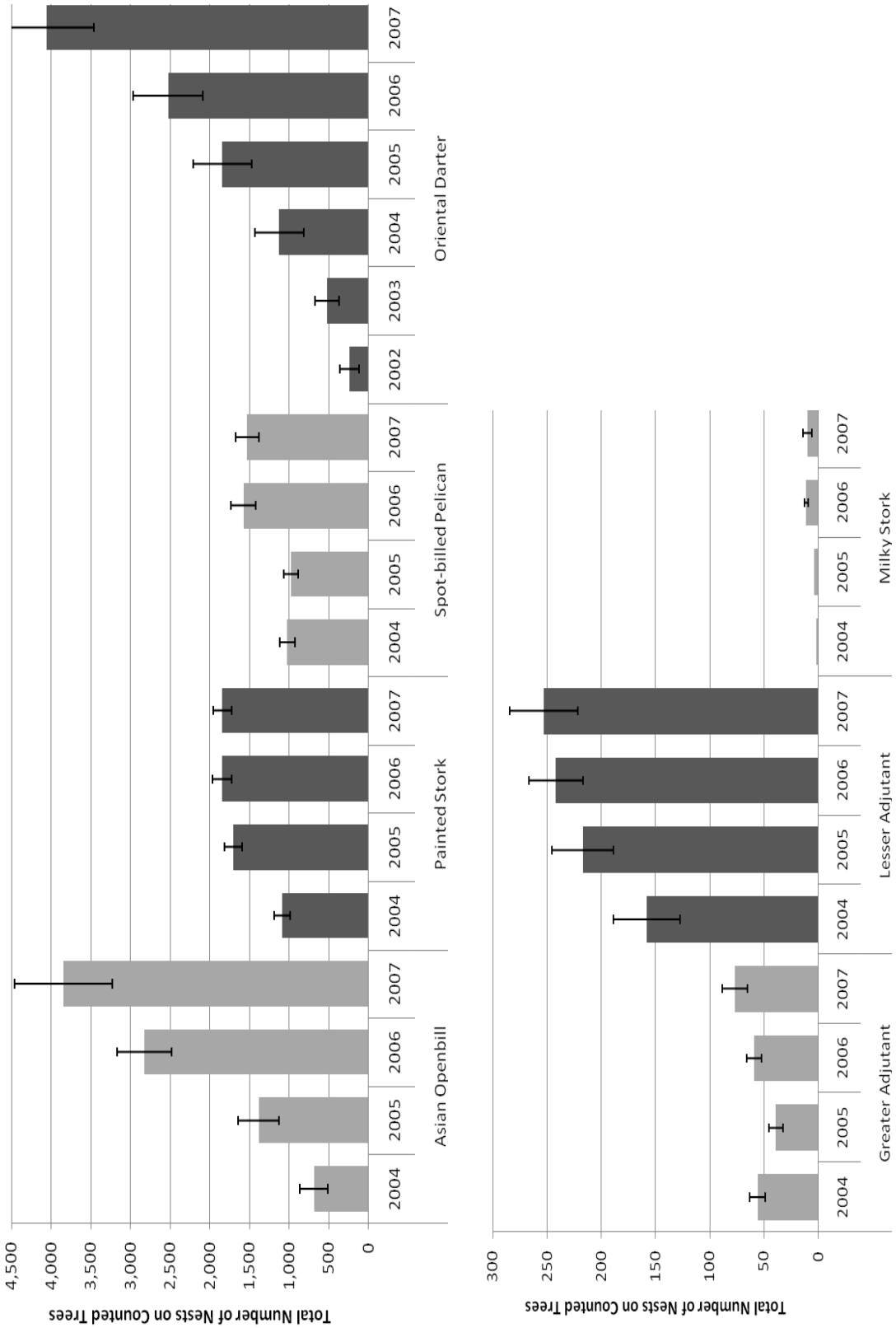


Table 14. Species population estimates based only on the visible counted trees recorded from the platforms

Species	Year	Mean Nests / Tree	Counted Trees	Counted Nests	Confidence Interval
Asian Openbill	2004	13.5	51	688	(514 - 862)
	2005	15.9	87	1386	(1132 - 1640)
	2006	18.7	151	2825	(2485 - 3165)
	2007	22.9	168	3844	(3229 - 4459)
Greater Adjutant	2004	1.3	42	56	(49 - 63)
	2005	1.4	28	39	(32 - 46)
	2006	1.3	44	59	(52 - 66)
	2007	1.8	42	77	(65 - 89)
Lesser Adjutant	2004	2.8	56	158	(127 - 189)
	2005	2.6	83	217	(189 - 245)
	2006	2.5	96	242	(217 - 267)
	2007	2.9	86	253	(222 - 284)
Milky Stork	2004	1	2	2	
	2005	1	4	4	
	2006	1.1	10	11	(9 - 13)
	2007	1.4	7	10	(6 - 14)
Painted Stork	2004	3.6	303	1089	(991 - 1187)
	2005	4.2	402	1707	(1596 - 1818)
	2006	4.8	385	1846	(1723 - 1969)
	2007	4.6	403	1841	(1724 - 1958)
Spot-billed Pelican	2004	6.0	172	1024	(932 - 1116)
	2005	5.1	192	978	(883 - 1073)
	2006	8.2	191	1575	(1419 - 1731)
	2007	8.8	173	1529	(1381 - 1677)
Oriental Darter	2002		4	241	(118 - 364)
	2003	18.0	29	521	(367 - 675)
	2004	22.1	51	1125	(819 - 1431)
	2005	24.3	76	1843	(1475 - 2211)
	2006	32.0	79	2527	(2087 - 2967)
	2007	27.2	149	4053	(3463 - 4643)

4.6. Total Colony size for Spot-billed Pelican, Painted Stork and Asian Openbill

For three species, Spot-billed Pelican, Painted Stork and Asian Openbill using the estimated colony areas for each (Section 3.4) and the equations in Section 4.4. Figure 6 and Table 15 show the final results. The data for Painted Storks is missing for 2005 due to problems interpreting the aerial photosfor that year. The estimated total colony areas are shown in Maps 5, 9 and 10.

The results show that the platform-based counts are under-estimating total population size by up to 50%. All three species have increased strongly since 2004, with Asian Openbills showing the most dramatic growth. Despite this, they appear not to be constrained by availability of nesting sites, because species are occupying only 20-50% of known trees within the colony area.

Figure 6. Total Colony Size 2004-2007. Confidence Intervals are shown.

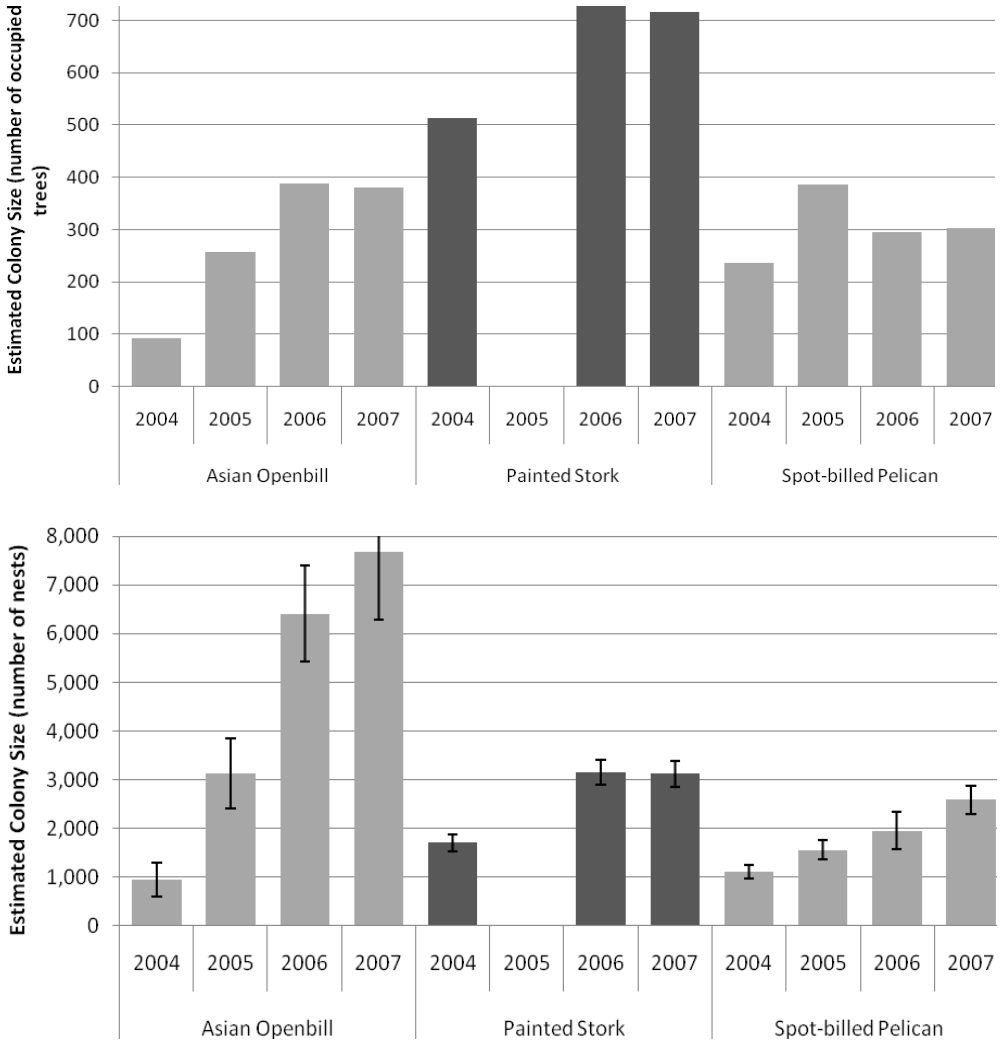
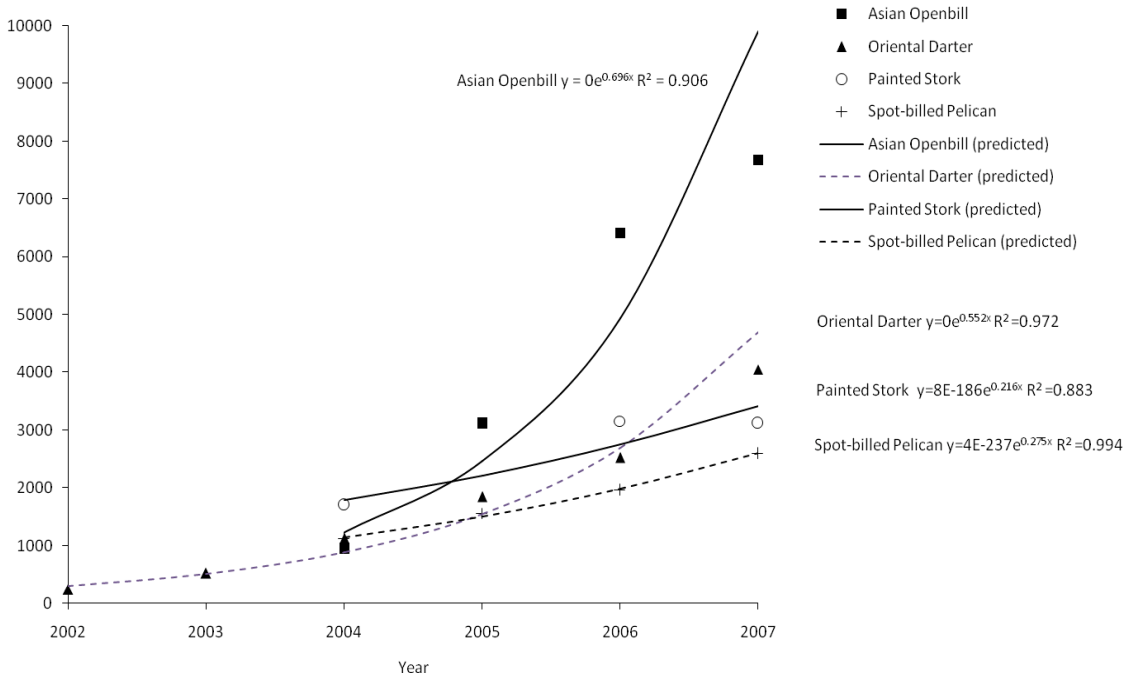


Table 15. Total Number of Occupied Trees and Nests for Spot-billed Pelicans, Asian Openbills and Painted Storks. Available Trees is the total number of trees within the colony area for each species.

Species	Year	Trees	Available Trees	Total Nests	Confidence Interval
Asian Openbill	2004	92	245	959.3279	(611 - 1307)
	2005	257	554	3122.875	(2403 - 3843)
	2006	389	845	6412.7	(5436 - 7390)
	2007	380	1133	7682.2	(6286 - 9078)
Painted Stork	2004	513	2867	1706.553	(1523 - 1890)
	2005				
	2006	732	3304	3154.7	(2905 - 3405)
	2007	717	3645	3121.2	(2854 - 3388)
Spot-billed Pelican	2004	237	842	1117.472	(977 - 1258)
	2005	387	1170	1559.046	(1365 - 1753)
	2006	295	785	1957.9	(1578 - 2338)
	2007	302	1123	2591.9	(2301 - 2883)

Figure 7 shows the population trend for four of the key species obtained by fitting an exponential growth curve to the nest data from 2002-2007. The figure shows the expected growth curve and the corresponding equation and correlation coefficient (R^2 value). For all four exponential growth curves are significant ($P<0.05$ in all cases) and explain a significant amount of the observed values (evidenced by the high R^2 values). The magnitude of the growth coefficient in each equation (as represented by the term preceding the x) varies between species and gives a measure of how quickly each species is increasing. Oriental Darter and Asian Openbills, which are smaller and shorter-lived species, exhibit high rates of increase, while Painted Stork and Spot-billed Pelican, which are larger and longer-lived, have much lower rates of increase. If the conservation program continues to be successful the population growth would be expected to continue until carrying capacity under current ecological conditions is reached.

Figure 7. Exponential Growth Curves for Asian Openbill, Oriental Darter, Painted Stork and Spot-billed Pelican.



5. PART FIVE: DISCUSSION

5.1. Comparison of Counting Methods: Platform Counts vs. Aerial Surveys.

Two distinct counting methodologies have been employed in the monitoring of the Prek Toal colonies over time, the platform based counts and the aerial surveys, both of which have specific advantages and disadvantages. The platform based counts which formed the basis of the original monitoring strategy are technically simple, inexpensive to implement and easily understood. They also provide highly effective colony protection, an integral function which can be seen as independent of their role in the monitoring regime. This method, however, generates enormous amounts of data, all of which must be processed and stored. There is also considerable potential for error implicit in the counting and mapping of trees, for example, through double-counting of trees or miscalculation of tree locations and distances. Most importantly, however, this approach does not allow for any estimation of the proportion of the total colony that is included in the platform counts. The monitoring teams attempt to count all occupied trees but in reality there is no means to determine the completeness of these counts, i.e. how many colony trees they may have missed. It is likely that the proportion counted varies each year, as the birds occupy different trees in different years, and consequently this may explain some of the observed population fluctuations (as seen in Figures 3-5).

The aerial surveys, on the other hand, provide accurate information on the total size of the colony and also allow for precise measurement of tree locations and the spatial dimensions of the colonies. However, this approach is technically demanding to carry out, considerably more expensive and requires large amounts of data processing using GIS to generate useable results. Apart from these logistical constraints, this method also does not allow for the identification of individual bird species and thus determining the species composition of the colonies through this method becomes a far more complex process when compared to straightforward platform counts.

By implementing both of these approaches simultaneously over a four year period and comparing the respective results it is evident that both methods are effective in detecting population trends within the key colony species. The apparent increases in average nests per tree, occupied trees and total number of nests indicated by the platform count data correspond to similar increases demonstrated by the aerial survey results. The aerial survey data allows us to calculate total population sizes for three key species, the Spot-billed Pelicans, the Painted Storks and the Asian Openbill, and in these population estimates provide evidence of far greater increases than those suggested by the platform counts. Total population sizes can be up to 100% greater than those estimated by the platform counts. Nevertheless, this comparison of methods does serve to validate the efficiency of the platform counts as a low-technology, inexpensive yet effective monitoring tool which will facilitate the detection of population trends over time. These trends can be linked directly to the protection and management strategies in place in Prek Toal and can be used to assess both the ecological integrity of the area and the overall success of the conservation initiative.

Consequently, the following simple indicators are recommended for long-term monitoring at Prek Toal (Table 16). These indicators can be collected using the platform count monitoring system and should provide a reasonable indication of trends at Prek Toal. This approach could be supplemented by aerial surveys at periodic intervals (such as every three years).

Table 16. Proposed Indicators for future monitoring

	Indicator	Measurement Method	Justification
1	Mean Number of Nests/Tree	Platform Counts: taken from peak survey for each platform	Platform counts provide a robust method to monitor the mean number of nests/tree. The mean number has been shown to increase as overall populations grow.
2	Number of visible occupied trees	Platform Counts: taken from peak survey for each platform	Shows the number of visible occupied trees counted from the platform. This number has been shown to increase as overall populations grow.
3	Number of satellite colonies	Platform Counts and information from other sites in Cambodia	Since 2004 species at Prek Toal have been expanding to new sites both within the core area and outside. This provides useful additional information indicating if overall numbers are increasing.
4	Total number of occupied trees in main Black & White colony	Boat surveys in wet season	Boat surveys in the wet season after the counting is complete can provide a useful indication of the size of the colony without requiring aerial surveys.

5.2. Colony Expansion 2001-2007

All of the key species appear to be undergoing large population increases, as indicated by more trees being occupied, more nests being observed in peak surveys and a higher average number of nests per tree being counted. Rates of increase are higher for some species than for others and some fluctuations in numbers do occur, but no declines have been detected. This implies that current conservation measures have been highly successful and that the Prek Toal colonies are being adequately protected and properly managed. Furthermore, the results presented in this report provide a number of additional points of interest specifically related to the breeding behaviour of the key species involved.

Whilst to the casual observer, Prek Toal can resemble an enormous and random array of species, the analysis has shown that species segregate considerably following relatively simple rules. Only Milky Storks and Greater Adjutants nest predominantly with another species, Painted Storks and Spot-billed Pelicans respectively. Within the main Black & White colony, Lesser Adjutants do nest with Painted Storks, however away from the main colony the nest independently. Asian Openbills have begun to nest with the Painted Storks, however it is not clear if they are nesting on the same trees or occupying the scrub beneath Painted Stork trees as water levels fall. Species nest independently in 83.9% of cases. As a consequence of these observed patterns the main Black & White colony can be divided up into species-specific areas relatively easily (see Maps 5, 9 and 10).

The observed population increases can be correlated with what is known about life history (Figure 7). Oriental Darters reach sexual maturity after 1-2 years, which explains the rapid observed population growth. This growth

commenced the year after the conservation program started and presumably was due to the increased protection afforded to the colonies. That is, the majority of the observed population increase is probably due to internal growth (i.e. returning offspring) rather than migrant birds from other areas settling at Prek Toal. Asian Openbills probably reach sexual maturity after 2-3 years, which explains the rapid growth seen since 2004 (i.e. 2-3 years after protection activities started). The slower rates of increase seen for the larger species, Adjutants, Pelicans and Painted Storks, can be explained because they can require up to 5 years to reach sexual maturity. The Painted Storks, for example, began to increase in 2005, four years after conservation protection activities started.

For some species, significant changes have been observed in the peak nesting date, with species becoming earlier each year. This is particularly true for the Oriental Darter and Spot-billed Pelican. The changes may be a behavioural response to increased protection: birds are less wary and more likely to start nesting when they arrive at Prek Toal.

The trends observed for the Pelicans raise some particularly interesting issues with respect to the relationship between colony protection and species-specific breeding ecology. Since the implementation of the protection and monitoring regime collection incidences have decreased in number and severity and eventually ceased entirely. However, in the early years of the conservation programme a number of major incidents occurred, the impacts of which are still becoming apparent today. Spot-billed Pelicans were disproportionately affected as they were heavily collected early in the 2001/2 season, with up to 100% colony loss, and again in 2002/3 season with up to 60% colony loss. Through the monitoring activities it was also possible to document the indirect effects these collection incidences had upon the colonies. After each instance the colony underwent further loss through egg predation by Large-billed crows, and also a "dislocation" effect whereby birds on trees which have been partially collected abandon their nests and nest desertion then expands to adjacent trees throughout the colony. High counts of Spot-billed Pelicans in nearby sites such as Ang Trapeang Thmor Sarus Crane Reserve in the weeks following these events suggests that the birds scattered and there is some evidence that they attempted a second brood at more remote sites but that breeding largely failed. These collection incidences in 2002 and 2003 season may explain the slower rates of increase in Pelican numbers in 2005-2007.

Although the colony is increasing, species occupy only 20-50% of the available trees, suggesting that there is considerable space for continued expansion (i.e. the birds are not tree limited). Increases have also been seen at other sites in Cambodia. Oriental Darters returned to nest in Preah Vihear in September 2006 for the first time since 2002. Sixty-five pairs of Painted Storks were observed nesting at Ang Trapeang Thmor Sarus Crane Reserve in Banteay Meanchey province in December 2006, the first recorded time for this species. As populations continue to increase the birds will be expected to expand to new sites and potentially recolonise old nesting grounds, if they are protected.

In Thailand, Asian Openbills breed successfully at several sites and have been increasing since the 1990s. More recently, Oriental Darters have begun to recolonise breeding sites on the Cambodian border and are now known from several locations across the country. On 10 October 2006, Painted Storks were observed building nests in Ban Laem District, Phetchaburi, the first recorded wild nesting in the Lower

Central Plain of Thailand. By early December these birds had failed, however their return suggests that further attempts may be made in future years. These birds may have originated from Prek Toal or from one of several Thai zoos that have resident free-flying populations of Painted Storks. Encounters with large waterbirds, such as Pelicans and Painted Storks has increased in recent years in the non-breeding season, suggesting migrations by birds from Prek Toal (all data from the Bird Conservation Society of Thailand, 2007 and Round and Gardner, *in press*).

Finally, although the population increases for key species outlined here represent a major conservation success for the most part, they also point to some future challenges which may arise as a direct result of rapidly increasing numbers of birds in the limited area of Prek Toal. One of the most pressing issues to be resolved in the future is encroachment of the Darters and cormorant colonies into the main Black & White colony. Not only does this increase competition for suitable nesting trees, and potentially for other resources also, but Darters and cormorants defoliate trees they nest and perch on, which can eventually lead to tree death over a number of years. This has been seen at Prek Toal, where, for example, Platform 6 has now been completely abandoned by the Darters because most of the trees have died. The continued Darter expansion into the main Black & White colony is therefore a concern, and appropriate management measures will need to be taken to ensure that the Darters do not start nesting on trees reserved for the Pelicans and Painted Storks. These measures might include the deployment of deterrents in August-October to prevent the Darters from establishing themselves in the main colony before the other species arrive.

5.3. Potential Future Challenges

The Tonle Sap Lake and the associated floodplain is the largest permanent body of fresh water in Southeast Asia and contains the most extensive wetland habitats in the Mekong system. The lake is one of the most productive freshwater ecosystems in the world (e.g. Bonheur, 2001; Lamberts, 2001; van Zalinge et al., 2003), both for fish and water snakes, and is extremely important for the Cambodian people as a source of food and income. It relies upon the flood pulse from the Mekong for its high productivity, which transfers sediment, water and other nutrients from upstream to the lake (Lamberts, 2001). During the flood water levels can rise from less than 1m to 6-9.5m, depending on the year, and the lake expands in area from 2,500km^2 to 15,000km^2 (Kummu et al. 2006). This floods the adjacent riparian forest and scrublands, which offers ideal conditions to many Mekong fish species for feeding, breeding and rearing their young (Poulsen et al., 2002). The lake provides other environmental services as well: it acts as a natural floodwater reservoir for the lower Mekong Basin, offering flood protection and assuring the dry season flow to the Mekong Delta.

The processes governing this unique hydrological system have been extensively modelled by the MCRS/WUP-FIN ("Modelling of the Flow Regime and Water Quality of the Tonle Sap") project (WUP-FIN 2003, Kummu et al. 2006). This project aimed to improve understanding of the physical, chemical and biological processes in the Tonle Sap in order to inform future management. The basic underlying models produced can be used to analyse the potential impact of future development scenarios on the environmental processes of the Tonle Sap lake.

Upstream developments in the Mekong, such as hydropower dam and reservoir construction, have already led to significant trapping of sediments and nutrients in reservoirs (Kummu and Varis 2007). These continuing developments will have an increasing impact on flood regime, timing and duration of flood in the Lower Mekong Basin and Tonle Sap. These changes may have a significant negative impact on the productivity of the Tonle Sap Lake and floodplain ecosystem due to (Kummu et al. 2006 and Kummu and Varis 2007):

- delayed flooding and a period of reduced fish growth;
- deduced flow velocities and incomplete transport of fish larvae and juveniles to the floodplain in the early stages of the flood;
- worsening dissolved oxygen conditions in the floodplain at the beginning of flooding due to a shortage of floodwaters;
- reduced floodwater levels in the wet season (caused by upstream dams capturing flood water);
- increased dry season water levels (caused by upstream dams releasing water in the dry season); and
- reduced supply of sediments and nutrients to the lake and floodplain system (caused by upstream dams capturing sediment that originally would have been transported to the lake).

Several of these factors are likely to have an effect on the Prek Toal bird colonies and specifically the flooded forest habitat within the core area. Overall, the decline in lake productivity might affect bird populations due to increased competition for food. The effects of changed dry season flow will increase the minimum water level in the lake from 1.57 m to 1.81 m above mean sea level, according to DHI (2004). This rise in water level would increase the minimum area and volume of the lake from 2500 km^2 to 2710 km^2 and from 1.62 km^3 to 2.37 km^3, respectively (Kummu and Varis 2007). Since the flooded forest, including the Prek Toal core area, is situated on the shore of the present dry season lake the increasing lake area may permanently flood part of the surrounding forest. This would prevent the forest from drying out for part of the year and may lead to long-term death of the main tree species. Under some scenarios up to half of the current Prek Toal core area would be affected. Given the abundance of dominant trees at Prek Toal, and the small proportion of trees used for nesting, this might be expected to cause a migration of the bird colony towards the upland forest areas, where there is currently unused nesting habitat. As a consequence, the future management of Prek Toal should consider active protection of the upland areas within the core area, so as to ensure that sufficient habitat is maintained if hydrological processes in the lake change as anticipated. Monitoring the impact of these changes on the birds' habitat will be a significant challenge in future years.

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