

Restoration of *Melaleuca* Swamp ecosystem for bird diversity in the Mekong Delta of Vietnam

Abstract

This paper conducts an original study to examine the restoration of an endemic tropical wetland for bird enrichment in the Mekong Delta. Recovery of swamp *Melaleuca* forest was a key driver provided an appropriately structural landscape and environment to enrich bird diversity in the study area. During the period 2003-2013, bird enrichment was increased to 159 bird species after a forest fire, happened in 2002, in which 15 waterbird species with 17,366 individuals; and populations of three waterbirds under the Global and Regional Endangered Lists with hundreds of individuals in UMT National Park. The recovery of forest and richness of birds were likely two important indicators of the successful restoration of *Melaleuca* swamp ecosystem in the area. Thus, relationships of six variables, involving *Melaleuca* recovery, bird richness, conservation values, technical awareness, tourism services, and wildfire, were considerable drivers needed to be understood for improving a sustainable management of forested wetland ecosystems. The restore of swamp *Melaleuca* forest can contribute an important role for the East Asian-Australasian Flyway of birds.

Keywords: driver, enrichment, flood, reforestation, water bird, wildfire

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Da B Tran, Tobias Matusch

Lecturer of Vietnam National University of Forestry, Vietnam

Correspondence: Da B Tran, Ph.D. Lecturer of the Vietnam National University of Forestry, Xuan Mai Town, Chuong My District, Hanoi, Vietnam, Email tranbinhda@gmail.com

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Introduction

Wetlands, one of the most important natural resources on the Earth, not only provide living sources for human livelihood all around the world, but also store valuable sources of biology, ecosystems, cultures, histories, and intensive economies. The world's wetlands are about 0.7-1.0 billion ha^{1,2} In regards to tropical wetlands, they are likely more important than other types of wetlands because they cover nearly half of the total wetland area on the Earth (about 0.34-0.48 billion ha²). Generally, wetlands are also important as carbon sinks for the global greenhouse gas emission [i.e. net carbon sinks of total wetlands on the Earth estimated were about 830,000 Mg C year⁻¹.³ Furthermore, tropical wetlands typically store more carbon than others, particularly the tropically forested wetlands.^{4,5,6,2} Carbon stocks of the *Melaleuca* ecosystem in Southern Vietnam were high [i.e. carbon densities ranging from 246.96 Mg C ha⁻¹ of regenerating *Melaleuca* forests on clay soil without peat to 784.68 Mg C ha⁻¹ of secondary *Melaleuca* forests on clay soil with peat⁷]. Successful ecological restoration can be potential for not only carbon sequestration but also biodiversity conservation.⁸ Since the last two centuries, the explosion of human population and economic occurred and large areas of natural wetlands has been over exploited and converted into different types of landuses. Accordingly, thousands of hectare of wetlands got lost and/or degraded [i.e. 50 % of conterminous wetlands of United States and Europe,^{9,10} recently hundred thousand ha of peat-wetland in Indonesia and Malaysia was converted into oil-palm lands,¹¹⁻¹⁴ or paddy rice in the Mekong Delta of Vietnam.¹⁵⁻¹⁷ On the other hand, many wetland areas around the world have been assigned as Ramsar's sites located in 150 countries with 1,674 wetland sites in total, covering 150 million ha.⁹ The Ramsar Convention on Wetlands has encouraged protecting, conserving, and restoring more than the sites engaged, because many wetland sites have been conserved to be added in the Ramsar's sites. The naturally tropical wetlands are always important to bird richness, particularly waterbirds because of the appropriate environment with warm weather all year, food and shelters availability for harboring and breeding. In addition, the tropical wetland like Mekong Delta of Vietnam is one of significant sites for migrant birds of the East Asian-Australasian Flyway.¹⁸

Historical study indicated that Mekong Delta of Vietnam was original four million hectares of primary swamp forest ecosystem, however its ecosystem currently remains only 0.068 million hectares.¹⁹ In regard to the U Minh Thuong (UMT) National Park, an endemic peat swamp *Melaleuca* ecosystem in the Mekong Delta, has been protected and restored since 1993 containing a huge richness of fauna and flora involving many rare and endemic species.²⁰ Unfortunately, in April 2002 a forest fire burnt large part of the park, including *Melaleuca* forest and peat. It was a serious shock and strongly affected the biodiversity. Since then, many efforts have been made to restore the endemic ecosystem from the significant degraded ones. After 10 year-restorations, it is likely that the park has been restored successfully. Additionally, an argument was considered that *Melaleuca* can be a key for sustainable development in the wetlands of Mekong Delta.²¹ Thus this study was conducted to examine and answer the questions: How does the enrichment process of bird diversity can be accomplished after *Melaleuca* has been afforested? In addition, the study further analyzed the awareness of wetland restoration and relationship of the variables of *Melaleuca* recovery and conservation for sustainable management in UMT National Park.

Materials and methods

Study area

The study investigated the site of U Minh Thuong National Park, which contains extensive wetland *Melaleuca* forests in the Mekong Delta of Vietnam, and is located at N 9o 31' - N 9o 39', E 105o 03' - E 105o 07' (Figure 1). *Melaleuca* forest on swamp peat land is an endemic ecosystem in the study area.

Forest field survey

The study analysed three *Melaleuca* forest types in the study area: degraded mature *Melaleuca* forest (coded U1), natural regenerating *Melaleuca* forest on peat (coded U2), and natural regenerating *Melaleuca* forest on mineral soil (coded U3). At the time of this study, the stands of U2 and U3 were over 10 year-old. A total of 9 plots were randomly selected for *Melaleuca* stand survey. The major

plots were set out as 500m² quadrats (20m×25m), and all trees with a diameter at breast height (DBH) ≥10cm were measured and recorded. Sub-plots also were set out as 100 m² quadrats (20m×5m) within the major plots to measure all trees with DBH <10cm and a total height of >1.3m (modified from Van et al.²²). To conduct the traits of *Melaleuca* forests, data on tree density, DBH and height (H) were recorded and analyzed for all standing trees. Basal area (BA) was also investigated with equation (1) (adapted from Jonson and Freudenberger²³):

$$BA = \frac{\sum_n^1 \left[\pi \times \left(\frac{DBH_i}{200} \right)^2 \right]}{S_{plot}} \times 10,000 \quad (1)$$

Where *BA* = basal area (m²/ha), *DBH_i* = diameter at breast height of tree *i* (cm), *i* = stand individual (*i* = [1:n]), *n* = number of trees of sample plot, *S_{plot}* = area of the sample plot (m²).



Figure 1 Study location of UMT National Park.

Sources: map from Department of Information Technology - Vietnam; satellite image from Google earth (free version).

Bird surveys

Bird surveys were conducted from 16 random plots which covered four habitats in the core area [i.e. *Melaleuca* stand, reed, opened wetland, and bird colony], and three transects crossing the buffer zone. We conducted the field surveys in three years within the same seasons (i.e. in May 2009, May 2011, and May 2013). The major field methods applied in the surveys were 'Timed Species-Counts' and 'Point Counts' which were used for counting the number of bird species, and 'Counting methods for specific groups' was also used to survey bird groups. We applied step by step on the basis of guidelines stated by Pomeroy & Tengecho²⁴ Pomeroy,²⁵ and Freeman et al.²⁶ 'Time Species-Count' was used to count the numbers of bird species over the certain time in two habitats (i.e. *Melaleuca* forest and open wetland), while 'Point Count' was used to conduct the surveys in grass land habitat. Additionally, other observations were also applied to count birds in night resting and reproducing places. The bird observations in each habitat were conducted in the morning (6:00-10:00 AM) and in the afternoon (3:00 - 6:30 PM) over three continuous days.

Name determination was based on 'A Guide to the Birds of Thailand',²⁷ and 'A Guide to the Birds of Southeast Asia'.²⁸ Species name and order were based on the research of Inskipp et al. We used 'Counting methods for specific groups' to investigate some specific groups of birds (i.e. *Ciconia episcopus*, and waterbird species) which usually rested at night and reproduced in breeding grounds within the study area. Crane population was counted four times in distance from a 13m height observation tower in the core zone of the park. Lesser Adjutant (*Leptoptilos javanicus*) was the main species of the

Crane group and was counted when they started flying in hot air lanes at 10:00 to 12:00 AM, daily. The number of individuals observed during the same counting time was regarded as the present number of the population. Counting night resting was conducted to record waterbirds at the shelters that counted 3 times (in three continuous days) at the bird colony. Counting time was from 4:00–6:30 PM when the birds returned to the sanctuaries and stayed overnight. The observations were conducted from a 10m height bird watching tower near the sanctuaries. The individuals were firstly identified to match with species, and then the total numbers of bird species were recorded.

Statistical analysis

Data of birds in 1999, 2000, 2001, 2002 and 2003 were collated from official reports of the UMT National Park, Birdlife International, and Care which all conducted different surveys in the park. One-way ANOVA tests were applied to conduct the traits of *Melaleuca* forests (including densities, DBH, height, and basal areas), and the populations of waterbirds. LSD post-hoc tests were also used for all pair wise comparisons between group means. Statistical analysis was undertaken using Microsoft Excel 2010 and the Statistic Program R. Causal Loop Diagram, a tool of System Thinking approach, was applied to conduct the connections between variables of *Melaleuca* recovery for bird enrichment developed with the Vensim Software Program (free version).

Results and discussion

Melaleuca swamp based restoration of the study area

Vegetation recovering of burnt areas in 2002: UMT National Park is a wetland area dominantly covered with *Melaleuca cajuputi*, however small areas of other habitats involving reed, open-water and grass were also existed in the core area. The household farming systems are allocated in the buffer zone, adding one additional type of habitat for bird communities in the study area. Before 2002, the park was a naturally seasonal flooded *Melaleuca* forest with high density, thick peat layer, and rich in biodiversity. However, also at that time UMT National Park was under high pressure due to illegal activities of local people (i.e. honey bee collection using smoke, animals trapping, charcoal producing, timber harvests). Due to there small extent, several small forest fires before 2002 affected just slightly the park. The fire in 2002 destroyed most of the National Park (i.e. the fire burned 1,138ha of mature *Melaleuca* forest on thick peat layer; 1,162ha of mature *Melaleuca* forest on thin peat layer; 403ha of mature *Melaleuca* forest on mineral soil; 104ha of young *Melaleuca* forest mixed with others; 405 ha of reed and grass; and about 11 million m³ of peat²⁹). The rest of *Melaleuca* area was also seriously affected and became degraded mature forest. Thus, vegetation cover of the park decreased dramatically by 2002's fire as illustrated in Figure 2. Since 2003, a series of activities to deal with the impacts of 2002's fire had been applied (i.e. strictly closed the park, improved the canal, dyke and gate systems to preserve water over the dry seasons, silviculture techniques for reforestation). Fortunately, since more than 10 years restoration the vegetation had been recovered gradually, and the land cover changes had been forwarding to more areas of open water, and young *Melaleuca* forest, but less area of mature *Melaleuca* forests than those before 2002's fire (Figure 2). It is likely that the current recovering vegetation can in future provide the positive ecosystem functions as a natural peat swamp *Melaleuca* forest.

Existing traits of *Melaleuca* stands: The stand densities of a typical *Melaleuca* forest varied considerably: there were 580 (±160), 9,833 (±2,266), and 6,733 (±1,985) trees ha⁻¹ for U1, U2, and U3,

respectively. The tree densities of regenerating forests (U2 and U3) were significantly higher than degraded mature forests (U1) ($\chi^2=4.6944$, $p=0.09563$) (Figure 3a and Supplementary). In contrast, U2 and U3 were dominated by trees with DBH <10cm (class U2C0, U2C1, U3C0, and U3C1). In contrast, U1 was dominated by trees with $10 \leq \text{DBH} < 15\text{cm}$, and equally by trees with other DBH classes (Figure 3b). Average DBHs of all stand classes were 12.93 (± 0.71), 5.88 (± 0.12), and 6.20 (± 0.14) cm for U1, U2 and U3, respectively (Figure 3c). There was a significant difference in DBH in the *Melaleuca* forest types ($\chi^2 = 113.66$, $p=2.2e^{-16}$). However, post-hoc test shows that there is no significant difference in tree DBH between U2 and U3 (Supplementary). In addition, most DBH of *Melaleuca* individuals was <30cm for U1, and <10cm for U2 and U3 (Figure 3d). Average total height of all stand classes was 9.69 (± 0.45), 5.68 (± 0.13), and 7.50 (± 0.25) m for U1, U2, and U3, respectively (Figure 3e). There was a significant difference in the total height of the *Melaleuca* forest types ($\chi^2=68.33$, $p=1.456e^{-15}$) (Supplementary). Furthermore, the top height of *Melaleuca* forest canopy of all classes was <15m (Figure 3f). The basal areas of the *Melaleuca* forest types were 8.93 (± 3.38), 30.14 (± 1.46), 23.02 (± 8.53) $\text{m}^2 \text{ha}^{-1}$, respectively. Furthermore, the basal area of U2 and U3 were significantly greater than U1 ($\chi^2=4.25$, $p=0.1194$) (Supplementary), that indicates the potential high biomass of U2 and U3. Generally, the existent traits of the *Melaleuca* forest in the study sites shown above confirm that the forest vegetation has been recovering and growing positively indicating that the forest can provide full functions of a fresh water forested wetland.

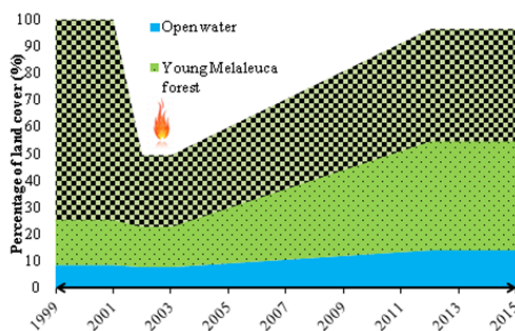


Figure 2 Summary of history line of *Melaleuca* forest cover change in UMT National Park.

Bird diversity of the *Melaleuca* swamp ecosystem

Existence of bird diversity: The results show that there were 159 species belonging to 46 families of birds recorded from the 2013’s survey in the study area, in which 67; 82; 119; 27; and 92 species were in *Melaleuca* forest, reed and grass, open water, sanctuary, and buffer zone habitats, respectively (Table 1). There were 19 out of 67 bird species which were only observed in the *Melaleuca* forest habitat; 21 out of 119 species were only observed in the open water habitat; and 4 out of 82 species were only observed in reed and grass habitats (Table 1). Additionally, there were 22 important bird species recorded in the study area which are in the national, regional and global endangered lists (i.e. IUCN 2012, CITES, and Vietnam’s Redbook 2007 (Table 1 and Table 2). It is likely that *Melaleuca* forest and open water habitats further attracted and harbored by local waterbirds and flyway-birds than other habitats. However, all five habitats are likely important to bird communities, particularly the bird species in the national, regional, and global endangered lists. Similar to other wetlands, the UMT National Park is also an important environment for waterbirds, thus we further quantified population of major waterbird species in the study area. There were 15 major waterbird species recorded and presented in Table 3. In which, two species (i.e. *Ardea alba* and *Egretta*

intermedia) were quantified as one group because they were difficult to be separated when counting. Four species had very big populations including *Phalacrocorax niger*, *Egretta garzetta*, *Nycticorax nycticorax*, and *Ardea alba* & *Egretta intermedia* (accounted for 6,508; 4,886; 2,745; and 1,540 individuals, respectively). The average population of *Anastomus oscitans*, *Plegadis falcinellus*, *Anhinga melanogaster*, *Ardea purpurea*, *Bubulcus ibis* were fewer (accounted for 449; 341; 299; 276; and 275 individuals, respectively), while the rest species had very small populations (i.e. population of *Ardeola bacchus*, *Phalacrocorax fuscicollis*, *Ardea cinerea*, *Dupetor flavicollis*, *Threskiornis melanocephalus* were 89; 79; 56; 39; and 9 individuals, respectively). Four out of the 14 species were in the lists of IUCN 2012, CITES, and Vietnam’s Redbook 2007, in which Little Cormorant (*Phalacrocorax niger*) had the biggest population (6,508 individuals) while Oriental Darter (*Anhinga melanogaster*) and Purple Heron (*Ardea purpurea*) had medium population (341 and 299 individuals), but Black-headed Ibis (*Threskiornis melanocephalus*) was only 9 individuals. In this small area (i.e. 8,038ha of core zone and 13,069 ha of buffer zone that equals to around 0.21 km^2), the UMT National Park has a significant richness of bird species, and particularly some of them are in the regional and global endangered lists. Comparing with Tram Chim National Park, a Ramsar site about 100 km far from UMT National Park, the bird diversity of Tram Chim is richer than UMT (i.e. 175 species of birds recorded in Tram Chim, of which 13 species are in the global endangered, threatened, or of special concern, particularly the species Sarus Crane (*Grus antigone*); this site contains one fourth of total birds in Vietnam.³⁰ However, it is likely that UMT has become an important stopover of waterbirds and migration birds (i.e. Mekong Delta of Vietnam is one of the important bird areas on the flyway of East Asia/Australasia.³¹

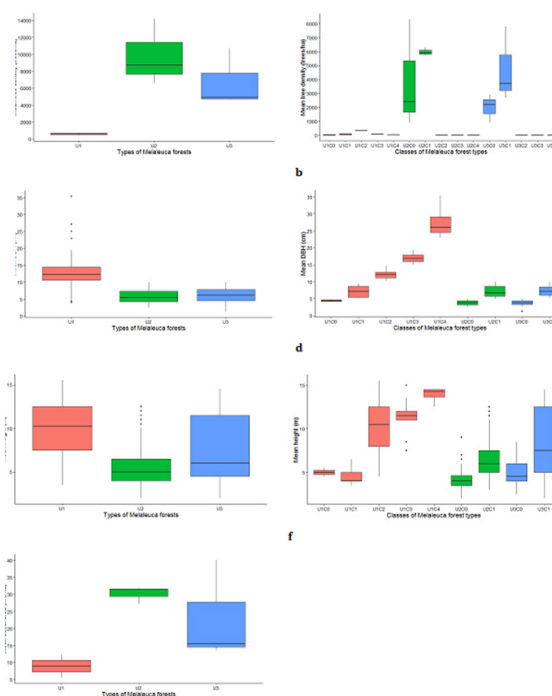


Figure 3 Traits of *Melaleuca* stands in the study area. Where as a & b–densities of *Melaleuca* forest types; c & d – tree diameter at breast height of the stands; e & f –height of stands; and g – basal area of *Melaleuca* forest types.

Note: U1- degraded mature *Melaleuca* forest; U2- natural regenerating *Melaleuca* forest on peat; and U3 - natural regenerating *Melaleuca* forest on mineral soil.

Table 1 Summary status of bird richness

Habitat	Numbers of bird species recorded						Numbers of bird species only in this habitat	Numbers of bird species in the 'global endangered list'
	VC	C	LC	U	rare	Σ		
Melaleuca forests	10	4	0	33	20	67	19	8
Reeds & grasses	21	13	0	33	15	82	4	8
Open water	24	19	0	40	36	119	21	17
Sanctuary	0	3	15	5	4	27	0	5
Buffer zone	nr	nr	nr	nr	nr	92	1	9

Note: data from the 2013's bird survey in UMT National Park; VC, very common; C, common; LC, least concern; U, un-common; nr, not recorded

Table 2 Summary of important bird species for conservation

Scientific name	Common name	Family	Conservation status			Site status recorded
			IUCN 2012	Vietnam's Redbook 2007	CITES	
<i>Accipiter badius</i>	Shikra	Falconidae	-	-	IIB	-
<i>Anastomus oscitans</i>	Asian Openbill	Ciconiidae	-	Vu	-	Br
<i>Anhinga melanogaster</i>	Oriental Darter	Anhingidae	NT	Vu	-	PR
<i>Aquila clanga</i>	Greater Spotted Eagle	Falconidae	VU	En	IIB	-
<i>Ardea purpurea</i>	Purple Heron	Ardeidae	-	-	-	PR
<i>Aviceda leuphotes</i>	Black Baza	Falconidae	-	-	IIB	-
<i>Circus aeruginosus</i>	Western Marsh Harrier	Falconidae	-	-	IIB	-
<i>Circus cyaneus</i>	Hen Harrier	Falconidae	-	-	IIB	-
<i>Circus melanoleucos</i>	Pied Harrier	Falconidae	-	-	IIB	-
<i>Elanus caeruleus</i>	Black-winged Kite	Falconidae	-	-	IIB	-
<i>Haliastur indus</i>	Brahminy Kite	Falconidae	-	-	IIB	-
<i>Ichthyophaga ichthyaetus</i>	Grey-headed Fish Eagle	Falconidae	NT	Vu	IIB	-
<i>Leptoptilos javanicus</i>	Lesser Adjutant	Ciconiidae	VU	-	-	PR
<i>Limosa limosa</i>	Black-tailed Godwit	Scolopacidae	NT	-	-	-
<i>Milvus migrans</i>	Black Kite	Falconidae	-	-	IIB	-
<i>Mycteria leucocephala</i>	Painted Stork	Ciconiidae	NT	Vu	-	-
<i>Pandion haliaetus</i>	Osprey	Falconidae	-	-	IIB	-
<i>Pelecanus philippensis</i>	Spot-billed Pelican	Pelecanidae	NT	Vu	-	Br
<i>Phalacrocorax niger</i>	Little Cormorant	Phalacrocoracidae	-	-	-	PR
<i>Plegadis falcinellus</i>	Glossy Ibis	Threskiornithidae	-	-	-	Br
<i>Ploceus hypoxanthus</i>	Asian Golden Weaver	Ploceidae	NT	-	-	-
<i>Threskiornis melanocephalus</i>	Black-headed Ibis	Threskiornithidae	NT	Vu	-	Br

Note: data from 2013's bird survey in UMT National Park; NT, near threatened; VU or Vu, vulnerable; En, endangered; IIB - species list in the Appendix II of CITES that requires an export permit or re-export certificate for trading. Br, breeding; PR, permanent resident.

Table 3 Quantity of important water bird species at the study area

Waterbirds	Numbers of birds (Individuals)	
	Mean	SE
<i>Ardea alba</i> & <i>Egretta intermedia</i>	1,540	56.2
<i>Ardeola bacchus</i>	89	13.3
<i>Ardea cinerea</i>	56	11.6
<i>Anhinga melanogaster</i>	299	10.4
<i>Anastomus oscitans</i>	449	21.5
<i>Ardea purpurea</i>	276	19.4
<i>Bubulcus ibis</i>	275	58.8
<i>Dupetor flavicollis</i>	39	3

<i>Egretta garzetta</i>	4,886	845.4
<i>Nycticorax nycticorax</i>	2,745	370.6
<i>Plegadis falcinellus</i>	341	61.9
<i>Phalacrocorax fuscicollis</i>	79	4.3
<i>Phalacrocorax niger</i>	6,508	234.1
<i>Threskiornis melanocephalus</i>	9	1.5

Source: survey data in May 2013

Waterbird enrichment in the study area over period 1999 – 2013: Data of bird surveys in 1999, 2000, 2001, 2002, and 2003 collated from the official and project reports were analyzed to compare with our bird surveys in 2009, 2011, and 2013 that aimed to address the

improvement of waterbird richness over the time from 1999 to the present, particularly after the deadly 2002's fire. The study results show that there were 14 waterbird species recorded in the period 1999 - 2001. The population of these species was small, in which 3 groups had around 1,000 individuals of each species (i.e. *Ardea alba* & *Egretta intermedia*, *Egretta garzetta*, and *Phalacrocorax niger*), but population of the other species were much smaller, particularly 4 species had under 20 individuals (i.e. *Ardea cinerea*, *Anhinga melanogaster*, *Mycteria leucocephala*, and *Threskiornis melanocephalus*) (Figure 4). In the period 2002 - 2003, there were 13 species observed in the study area, in which only two species had a population of around 500 individuals (i.e. *Egretta garzetta* and *Nycticorax nycticorax*), while population of the other species was very small that was likely of the consequence of the 2002's fire (Figure 4). Comparing with the before period, population of waterbirds in period 2002 - 2003 dramatically decreased, and was significantly smaller ($\chi^2=87.9865$, $p=7.707e-06$) (Supplementary). Interestingly, not only one more waterbird species was recorded, but also quantities of these species dramatically increased in the period 2009-2013 in comparison with the previous periods. In despite of two species (i.e. *Threskiornis melanocephalus* and *Mycteria leucocephala*), populations of waterbirds in the period 2009-2013 were significantly greater than that of both previous periods ($\chi^2=87.9865$, $p=7.707e-06$) (Supplementary), particularly the populations of 4 groups increased by thousands of individuals over the periods (i.e. *Ardea alba* & *Egretta intermedia*, *Egretta garzetta*, *Nycticorax nycticorax*, and *Phalacrocorax niger*). In addition, populations of the species in global and regional endangered lists also increased from hundreds to thousands of individuals [i.e. *Anhinga melanogaster*, *Ardea purpurea*, and *Phalacrocorax niger*]. In addition, there were 14 new bird species recorded in the 2013's survey when collated the data recorded in the 1999's survey.³² Generally, the increase of waterbird populations over the periods, especially after the deadly 2002's fire, is not only the improvement of bird richness, but also a positive feedback to the restoration of UMT National Park. It is likely that populations of waterbirds will be continuously growing up.

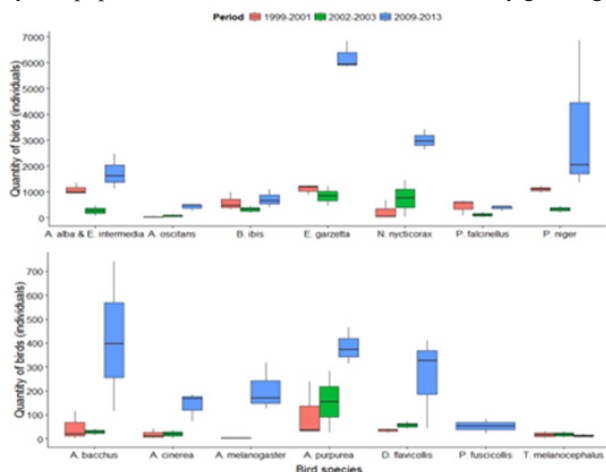


Figure 4 Comparison of quantities of waterbirds in three periods 1999 - 2001, 2002 - 2003, and 2009 - 2013.

Linkage between *Melaleuca* swamp ecosystem restoration and waterbird enrichment: An important key aspect of restoration of the swamp *Melaleuca* ecosystem in the study area was the recovering vegetation of the landscape, particularly after the deadly 2002's fire which burned 3,212 ha of *Melaleuca* forests.⁴¹ The results (Figure 5) show that the mature *Melaleuca* vegetation reduced from 4,216ha as primary forest before 2002 to 1,513ha as degraded forest right after

the fire, but increased to 2,366ha of mature forest in 2013. At the same period, young *Melaleuca* vegetation increased rapidly from 957ha at the time before the 2002's fire to about 2,300ha of seed regenerating *Melaleuca* forest in 2013. Additionally, open-water area (including reed and grass) also rose from 476 ha before 2002 to 787ha in 2013. Parallel with the changes of land cover of the landscape, the total population of waterbirds also changed which reduced from 4,842 individuals recorded before 2002 to 3,003 individuals in period 2002-2003, but dramatically increased to 17,366 individuals in the period 2009 - 2013 which 3.5 times greater than numbers of birds of before states ($\chi^2=12.7348$, $p=0.0017$) (Figure 5 and Supplementary). It is likely that the enrichment of waterbirds is based on the expanse of open-water area and young *Melaleuca* forests. Furthermore, during the period 2003-2013, the core area of the park was under a permanent inundated condition by the control of canal, dyke and gate system to preserve water over the years to prevent forest fires. Generally, there is a relationship between waterbird enrichment and the restoration of the swamp *Melaleuca* ecosystem. The bird richness has been improved by the change of landscapes due to a serious disturbance – the deadly 2002's forest fire. Accordingly, deforestation does not always have negative consequences, but can provide positive outcomes for biodiversity.³³ Hydrologic restoration had no negative effect to bird diversity, but enriches bird breeding of species *Protonotaria citrea* in the forested wetlands of Illinois, USA.³⁴ Additionally, a forestation influenced bird species composition by altering the vegetation structure.³⁵ That is likely an evidence to convince water preserve could not affect bird communities in the study area. Increasing open-water area over the periods could be one of the factors for bird enrichment. It is important that the diverse mosaics of wetland habitats influence the determinants of waterbird distribution and abundance at all scales.³⁶ Additionally, mosaic landscapes are likely a suitable habitat for forest bird species.³⁷ This argument is connecting the recent landscapes of the study sites that offer a higher variety and mosaic by four types of habitats of the core area during the restoration period after the 2002's fire.

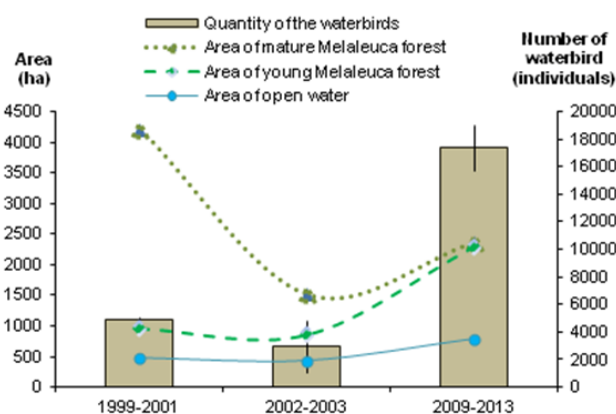


Figure 5 Changes of the vegetation and total quantity of waterbirds over period 1999-2013.

Awareness of the successful restoration of *Melaleuca* swamp ecosystem for sustainable management: It is considerable to conclude that the restoration of *Melaleuca* swamp ecosystem in the study area has been successful. The landscape and associated abundance of bird species were significantly changed by the fire disturbance, but it has been restored by the recovery of vegetation, particularly the recovering of swamp forest. It is likely that the structure of the wetland landscape has been reconstructed step by step in a balance of *Melaleuca* area, open-water area, and canal systems.

This success is confirmed by the enrichment of bird diversity, and the storage of peat and carbon pools. Worldwide, most studies conducted the ecological restoration success measuring only one of three general criteria which are diversity, vegetation structure, and ecological processes.³⁸ In this study, a Causal Loop Diagram of *Melaleuca* swamp ecosystem was developed to aware the success of wetland restoration in the study area, and to understand the connections of variables identified through the system thinking approach. There are six major variables linked together that need to be aware to understand for sustainable management of the restored *Melaleuca* swamp ecosystem [i.e. *Melaleuca* recovery, bird richness, conservation values, technical awareness, tourism services, and wildfires (Figure 6)].

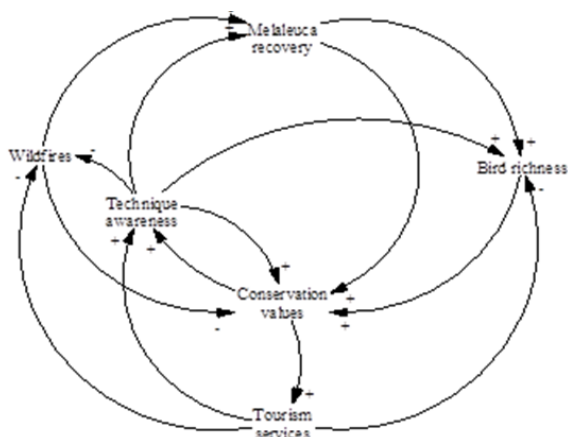


Figure 6 A Causal Loop Diagram of the *Melaleuca* swamp ecosystem restoration.

The variables were identified within a boundary of the management activities of the park itself. Figure 6 contains both the reinforcing and balance loops that named ‘*Melaleuca* recovery for conservation Loops’. These loops describe the role of *Melaleuca* recovery to conservation values, particularly after the 2002’s fire. *Melaleuca* had been reforested improving the conservation values (i.e. forest cover improvement and peat protection that have been stocked a big amount of carbon ranged from 246.96 Mg C ha⁻¹ to 784.68 Mg C ha⁻¹ of the *Melaleuca* forest in the clay soil without peat, and the *Melaleuca* forest in the clay soil with peat, respectively⁶). Additionally, *Melaleuca* recovery plays an important role of bird enrichment that has been added further value for conservation of UMT national park. Conservation values are likely high net social benefits (i.e. the biodiversity protection value of a typical wetland in the Mekong Delta was estimated from USD 0.52million to USD 1.84million³⁹). Furthermore, the improvement of conservation can lead the development of tourism services – one of important economic sectors (i.e. a study highlighted the importance of matching supply and demand between each ecosystem service and its beneficiaries for economic values.⁴⁰). But, tourism services are likely containing both positive and negative affects to the conservation of protected areas. Tourism activities can provide finance and encourage the awareness of people to conservation activities if tourism is under the control. In contrast, if tourism is not well managed bird richness can be strongly affected, and forest fire can be more vulnerable, and at high risks. Technical awareness also is an important aspect to improve *Melaleuca* recovery. After the 2002’s fire, series of techniques were applied to restore the *Melaleuca* ecosystem. One of the effective solutions applied was the preservation of water over the dry season by controlling the canals, dykes and gates that aimed to prevent fire.^{41,42} There has been no more fire happened since 2003 that fosters the improvement of *Melaleuca* forest cover. However, preserving water

permanently also causes the fall down of *Melaleuca* stands (personal record). To improve the restoration of *Melaleuca* swamp ecosystem, an endemic landscape of the Mekong Delta, it needs to understand the variables and to manage them under a balance of relationships aiming at conservation than services. A study conducted in Mexican non-coastal protected wetlands indicated that ‘identification of information gaps and conservation priorities’ was useful for both management and research,⁴³ but that is likely not completed. A systematic understanding is likely further appropriate approach for sustainable wetland management.

Conclusion

By undertaken original field data, and utilization of the secondary databases, this study examined the restoration of an endemic tropical wetland for bird enrichment in the Mekong Delta of Vietnam.

Over ten years, the *Melaleuca* swamp ecosystem of the study area has been successfully restored. The recovery of *Melaleuca* forest is the key success of the restoration. *Melaleuca* reforestation provides an appropriately structural landscape which mixed the vegetation of forest, reed, grass, and open-water areas. Bird diversity has been enrichment over period 1999-2013 with 159 bird species, in which 15 waterbirds species with total of 17,366 individuals recorded recently in the area; and three out of four waterbirds under the global and regional endangered lists having big population, including 299 individuals of *Anhinga melanogaster*, 276 individuals of *Ardea purpurea*, and 6,508 individuals of *Phalacrocorax niger*, in average of the period 2009-2013. The bird richness is considered an important indicator to react the successful restoration of *Melaleuca* swamp ecosystem. A Causal Loop Diagram of ‘*Melaleuca* recovery for conservation Loops’ with six variables involving *Melaleuca* recovery, bird richness, conservation values, technical awareness, tourism services, and wildfire was developed to further understand their relationship. This result can help for future sustainable managing fresh forested wetland ecosystems in the tropical region.

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Conflicts of interest

The authors declare that they have no competing interests.

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